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Evaluation of European District Heating Systems for Application to Army Installations in the United States

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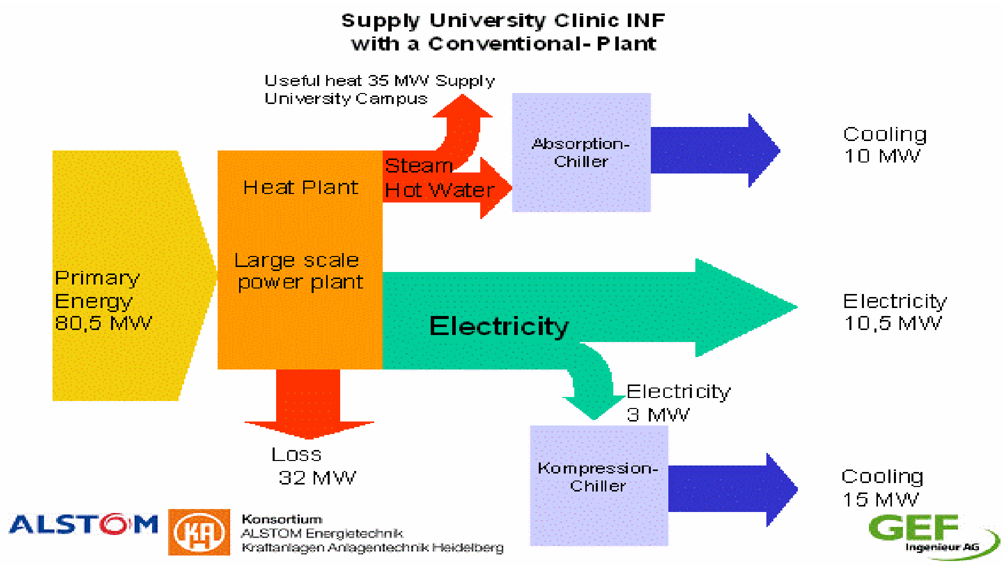
July 2006



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Final Report

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Abstract: “District heating” (DH) is much less common in the United States than in Europe, where it is widely accepted as a method for providing safe, efficient, low-cost heating energy to the consumer. This study investigated and evaluated experiences with DH systems in Europe, focusing on systems in Germany and Finland, to offer recommendations for improving U.S. Army DH systems in the Continental United States (CONUS), specifically to evaluate the feasibility and economics of converting existing systems, to reduce heat and water losses, to improve thermal efficiencies, and to reduce the high cost of pipe replacement. This work investigated technical details of energy plant and DH systems, including some U.S. Army and municipal district heating systems in Germany, and recommended that CONUS Army central energy plants be investigated for conversion to cogeneration facilities, with sliding temperature-variable flow of medium/low temperature hot water as a heating source.

Executive Summary

"District heating" (DH) is much less common in the United States than in Europe, where DH is the widely accepted as a method for providing safe, efficient, low-cost heating energy to the consumer. This study investigated and evaluated experiences with DH systems in Europe, focusing on systems in Germany and Finland, to offer recommendations for improving Army DH systems in CONUS, specifically to evaluate the feasibility and economics of converting existing systems, to reduce heat and water losses, improve thermal efficiencies, and reduce the high cost of pipe replacement. This work investigated technical details of plant and DH systems, including some U.S. Army and municipal district heating systems in Germany.

District heat has made a considerable contribution to energy conservation and environmental protection in Europe. In European cities, energy is normally provided by a cogeneration facility that provides the community with both electricity and heat. Many DH systems once configured to use steam as the heating media are now converting to medium or low temperature hot water, thus reducing operations and maintenance (O&M) costs. Some plants have successfully reduced plant labor force through the use of improved monitoring and control equipment. Some facilities use a variable temperature-variable flow of medium/low temperature hot water (below 130 °C) for a heating source, allowing the use of less expensive, more efficient piping material, which reduces heat losses to ground, and is a safer medium with less potential to flash to steam at a leak. Much of the piping has built-in leak detection, which, in the alarm mode, identifies the exact location of the leak (and reduces repair costs). U.S. Army installations in Germany have either heating-only plants, or are connected to the local utility, which provides the required heat.

DH produced by the traditional heat-only plant or by a combined heat and power (CHP) plant has an enormous potential for increasing thermal efficiency and fuel reliability, and reducing environmental impacts. The advantages of these combined technologies are that: (1) both are proven technologies; (2) it is relatively simple to use these technologies to satisfy a substantial part of a community's energy demand; and (3) the high efficiencies of these technologies reduce pollution emissions, including

greenhouse gas emissions. The use of DH heating systems is especially valid in high population density areas.

DH systems can provide a community with a more operationally efficient and economically competitive heat supply than can an individual heating system. This is particularly true when the DH system is supplied from CHP plants, which substantially increases the system's overall efficiency. Since large CHP plants are normally equipped with flue gas cleaning equipment that removes particles, sulphur dioxide, nitrogen oxides and other unwanted emissions, the system offers environmental improvements in reduced emissions of air pollutants.

For these reasons, DH plays an important role in filling space- and water-heating demand in many European cities. For CHPs, these heat sources act as the condenser in the making steam to power turbines for electrical generation. The use of this normally wasted heat by-product from the power-generating process almost doubles the efficiency of the typical fuel-fired electrical generation plant. This technology is common in Europe. Half the population of Finland is served by DH systems, and many cities in Germany, Denmark, and other countries use DH for most of their heating needs.

After an extensive review of German DH systems and solicited inputs from experts in the field, DH systems are characterized as follows:

1. **Efficient Operations:** The European district heating systems normally operate as a heat-only, or as co-generation systems, generating electricity as well as providing heat to their customers. The CHP plant efficiency is in the range of 70 to 80 percent, about double that of a modern electrical generation plant, which has an efficiency of approximately 40 percent.
2. **Plant Conversions:** Many DH systems once configured to use steam as the heating media are now converting to medium or low temperature hot water, thus reducing operations and maintenance (O&M) costs. The hot water heating medium allows the use of less costly piping, which also has superior insulating properties. Additionally, the lower temperature hot water improves the electrical generation capability. In many cases, plants are converting to a variable water temperature operation, which controls the return temperature to maximize power production and minimize heat losses. With variable hot water, these central energy plants can generate more electrical energy from

the fuel they burn with less heat lost in the distribution system. Hot water systems experience fewer problems related to expansion and contraction in the piping system, have fewer corrosion problems, and are easier to control, all of which result in low maintenance costs. New types of piping includes built-in leak detection systems that facilitate quick and easy repairs, which also reduces repair costs. The application of hot water heating and the new piping reduces the overall life cycle cost (LCC) of central heating systems.

a. Conversions of steam systems may require some changes in the pipe distribution and new requirements for heat exchange equipment at the customer interface and in the central heating plant. The lower heat carrying capacity of hot water as compared to steam will require changes in the distribution system. (Any changes must be verified through thermal and hydraulic analysis.)
b. The steam supply pipe is normally large enough for distribution of the hot water. The returning condensate piping often requires a supplement pipe to bring the hot water back to the power plant. In some cases, piping that served as condensate return requires replacement. The pipe may be corroded to the extent that it has already passed its useful life, in which case a new larger pipe will actually be a less costly solution repair of the existing condensate return.
c. The new hot water system should operate with a lower temperature spread since the steam to hot water building interfaces will be replaced with efficient and compact water-to-water substation heat exchangers sized for the new temperatures.
d. Most of the district heating systems observed varied the supply hot water temperature depending on the load. In the summer the hot water is used mostly to heat domestic hot water and can thus be lower in temperature than in the winter when the water is used for building heat. This variable temperature control reduces the distribution heat losses and allows for an increase in the quantity of electricity produced by a back pressure steam turbine or by an extraction-condensing turbine.

3. **Reduce Operations Costs:** In some cases, the central energy plant labor force was successfully reduced by the use of improved monitoring and control equipment. Remote satellite plants are typically unmanned; one (1) operator at the central control station monitors the operation of the remote equipment. Other than for maintenance, staff need only visit the remote sites every 1 to 3 days to observe the equip-

ment performance. It was not uncommon to have a shift crew of four to five workers run large (300 to 600 MW) power plants that before required a crew of 20 or more workers.

4. **Summer Operations:** If the summer heat load is sufficient at an installation, the use of a CHP system rather than a heating-only power plant:
   a. Would reduce the use of energy resources since CHPs are more energy efficient.
   b. Would improve energy security due to on-site electrical generation and the use of abundant fuels, but ...
   c. Would require a high pressure boiler for the electrical generation (perhaps higher pressure than currently installed), steam turbines, electrical generators, and electrical power conditioning equipment.
   d. Would require additional training for operating personnel to acquire skills for good performance of the electrical equipment.
   e. Would require increased O & M cost at the plant (for the new equipment) while lowering the amount of electrical energy purchased.
5. **Heating Distribution:** Use of a variable temperature-variable flow medium/low temperature hot water (below 130 °C) for heating source:
   a. Reduces heat loses to ground by decreasing the temperature differential.
   b. If generating electricity, can extract energy at a lower pressure, and create return temperatures low enough to help condense steam discharged from the turbines.
   c. Is a safer medium with less potential to flash to steam at a leak.
   d. Allows use of less expensive, more efficient piping material. The lower temperature allows the use of polyurethane foam insulation that has a better insulating value of other insulation materials at a lower cost. Table E1 lists types of common underground pipes for comparison.
   e. In most cases, dispenses with the need for higher temperature water/steam. (Separate smaller boilers would suffice for exceptions.)
6. **Leak Detection in Piping:** Distribution pipes are replaced when they begin to leak. These pipes have an automatic leak detection wire buried within insulation to monitor leaks. In its alarm mode, the leak detection system identifies the exact location of the leak, which significantly reduces repair costs.

Table E1. Underground pipe system.

Pipe Type	Advantages	Disadvantages
Polyurethane foam insulated bounded pipe	• Cost-saving laying of the pipes • Directly buried in sand • No expansion compensation required up to dn300 • Minimal man-holes required • Low preventive maintenance • Connection of new junctions under pressure possible • Pre-cast fittings available • No corrosion protection required	• Limited for temperatures below up to 285 °F/140 °C
Steel-jacketed pipes	• High temp. Up to 660 °F/350 °C	• Very high installed costs • Corrosion protection required • Complex expansion compensation, with anchors and numerous man-holes required • Leak detection difficult making maintenance costly

7. **Building Heat:** Steam is not the best heating medium inside buildings because:
   a. Hot water is safer and easier to control, and hot water systems require less maintenance.
   b. It allows the use of medium/low temperature hot water for site distribution.
   c. Hot water systems can contribute significantly to overall energy system efficiencies. In Finland, the FläktWoods Group has developed a high efficiency building heating systems called ThermoNet/ECONET, which is a packaged liquid-coupled heat recovery system used for building heating and cooling. The recovered energy is used to reduce the heating energy use from the DH system. Some applications use the DH hot water fluid directly without heat exchange in the heating, ventilating, and air conditioning (HVAC) system coils. This results in a lower return water temperature so that the supply water temperature need not be as hot. These systems have fewer components (pumps, valves, etc.) and are smaller than traditional HVAC systems. They provide can increase heat recovery efficiency by 15 to 20 percent compared to the normal "run-around" coil heat recovery system.
8. **Reduction in Energy Consumption:** Studies have shown that there is up to 30 percent reduction in energy consumption from converting to hot water from steam. These energy savings are most preva-

lent in the distribution system attributed to the reduced losses across the piping.

9. **Cost and Availability of Low - Medium Temperature Hot Water Piping:** The piping required for low – medium temperature hot water piping is readily available in the United States and can be as much as 30 percent cheaper than piping required for steam distribution systems.
10. **Centralized vs. Decentralized Heating Plants Applied to U.S. Army Installations:** In the past 30 years, typical heating systems constructed have been those that served individual or small groups of buildings. These decentralized heating plants are generally fueled by natural gas, which requires a simple delivery system, produces low environmental emissions, and has been available at a reasonable cost. The cost of natural gas has recently increased significantly and is expected to remain high. Also the maintenance staffs on military installations have been reduced over the years while maintenance needs of decentralized equipment have increased. Furthermore, each unit of decentralized equipment has more control components than does equipment that receives heating and cooling energy from a central plant. Today's central heating systems are efficient and reliable, and provide flexibility of fuel choice. (They can be constructed to burn coal, oil, and natural gas—whichever is the most competitive.) Low temperature heating distribution systems avoid many of the problems associated with steam and high temperature distribution system. The can be controlled to avoid energy waste by decreasing the hot water temperature on days when small amounts of heat are needed, thereby avoiding overheating spaces due to poorly operating controls. If the existing decentralized equipment is over 20 years old and approaching the end of its useful life, an evaluation of a centralized system to replace the old equipment is recommended. This evaluation would assess:
    a. the unique issues and circumstances of the situation,
    b. the installation energy density
    c. the life-cycle costs of upgrading the existing heating system vs. the central system.
    d. the issue of fuel availability
    e. problems of installing new underground pipes could be clarified and properly reflected in the central heating system cost.
    f. operations and maintenance concerns.

Contents

Figures and Tables

Figures

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Preface

This study was conducted for the Office of the Assistant Chief of Staff for Installation Management (ACSIM) as part of the Technology Standard Group (TSG). The technical monitor was Phillip Columbus, ACSIM.

The work was managed and executed by the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). Credit is given to the following individuals for significant technical contribution into the document: Alfred Woody from Ventilation/Energy Applications, PLLC, Dr. Stephan Richter from GEF Ingenieur AG, Dr. Jorg Matthies from MVV Energie, Daniel Droste from MVV Energie, Dr. Reijo Kohonen from FläktWoods Group, and Donald Fournier from University of Illinois. Appreciation is owed to the following people for visits to their company/installation: Dr. Andreas Schleyer - GEF, Dr. Christian Veenker – MVV Energie, Dr. Jorg Matthies – MVV Energie, Claus Eisgruber – MVV Energie, Dr. Helmut Stadtmuller – SWM, Dr. Stefan Birle – SWM, Dr. Torben Keck – SWM, Karl Zepf – FUG (Former Energieversorgungr Schwaben AG), Dr. Dieter Danks - FUG, Dr. Peter Humboldt – FUG, Dr. Michael Schmidt – University of Stuttgart, David Yacoub – IMA/EURO, Dieter Gerber – Bamberg Directorate of Public Works, Ms. Regina Kranz – Illesheim Directorate of Public Works. Dr. Tom Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Dr. Paul A. Howdyshell, CEERD-CV-T. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Richard B. Jenkins, and the Director of ERDC is Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
Acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
British thermal units (International Table)	1,055.056	joules
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
Feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (U.S. liquid)	3.785412 E-03	cubic meters
Inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
ounces (mass)	0.02834952	kilograms
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pints (U.S. liquid)	4.73176 E-04	cubic meters
pints (U.S. liquid)	0.473176	liters
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

"District heating" (DH) is much less common in the United States than in Europe, where it is widely accepted as a method for providing safe, efficient, low-cost heating energy to the consumer. In a DH system, energy is normally provided by a cogeneration facility that provides both electricity and heat to a group of buildings or community. District heating systems offer many benefits over "distributed heating" systems, which locate smaller heating and cooling systems in individual buildings or even single dwelling units. DH systems are generally more efficient, less expensive to construct and maintain, and require fewer operations and maintenance personnel that alternative distributed heating systems.

A number of U.S. Army installations in the Continental United States (CONUS) and Germany use central energy plants to heat and (in some cases) to cool buildings. In CONUS, these systems may consist of one large or several smaller central plants, which provide both heating and chilled water. Moreover, many of the Army's large central energy systems (heating/cooling plants and distribution systems) are aging. These systems have already exceeded their expected useful lives and are in a failed or failing condition. Their condition threatens mission performance and readiness through increased operation and maintenance (O&M) costs, significant energy losses, and possible catastrophic failures.

Many U.S. Army installations in Germany are served by DH systems, either through connection to a large network or through on-site third party central plants located on the installation, which provide heating only. This study was undertaken to investigate and evaluate experiences with DH systems in Europe, focusing on systems in Germany and Finland, and to offer recommendations for improving U.S. Army DH systems in CONUS, specifically to evaluate the feasibility and economics of converting existing systems, to reduce heat and water losses, to improve thermal efficiencies, and to reduce the high cost of pipe replacement.

1.2 Objectives

This objective of this work was to investigate the technical details of European energy plant and DH systems, including some U.S. Army and municipal district heating systems in Germany, and to make recommendations regarding the application of current DH technologies to CONUS Army central energy plants

1.3 Approach

This report provides information gathered from discussions with district heating experts from the United States, Germany, and Finland, as well as data obtained from visits to several operating systems in Germany in October 2005, including:

- A review of older and newer systems operating in the United States, particularly at Army installations, as well as modern District Heating (DH) systems (providing heat) and combined heat and power (CHP) systems (providing both heat and electricity) operating in Europe (Chapter 2).
- A discussion (targeted at decisionmakers and system designers) of insights into DH and CHP systems, major components, supplemented with examples of implementation in Germany (Chapter 3).
- A discussion of the advantages and technical feasibility of conversion from older, steam-based DH systems to modern, sliding-temperature hot water DH systems (Chapter 4).
- An elaboration of the economic factors and operating and ownership considerations of the conversion (Chapters 5 and 6).
- A discussion (targeted at the general audience) of the qualitative highlights, advantages, and disadvantages of such modern DH system technologies as low- and sliding-temperature DH systems, CHP vs. heating-only DH systems, biomass-fired systems, and the conversion from steam to hot-water DH systems and/or combinations of low-temperature DH systems with heat recovery (Chapter 7).
- An outline of the applicability of modern European DH systems to U.S. Army installations (Chapter 8).

1.4 Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) at URL: http://www.cecer.army.mil

2 Overview of DH Systems

2.1 Central District Heating Systems Operating in the United States

2.1.1 General Discussion

There are a number of DH systems operating in the United States. They fall into two major categories. The first are type can be found in “older” northern cities that installed the heating pipe distribution system over 50 years ago in what is currently their downtown areas. At that time, the primary source of heating energy was coal, and the burning of coal at a central location was the most economical method of delivering heat to these buildings. Current natural gas availability has enabled small heating equipment to serve a building or an area within the building. This arrangement has become a competitive solution to district heating systems because natural gas requires a simple delivery system, is clean to operate, and has low maintenance costs. In these “old” cities, DH systems commonly use steam heat, which is characterized by high operating and maintenance (O&M) costs.

The second category of DH systems can be found in institutions that have a collection of buildings located close together to minimize the distribution pipe cost, e.g., college campuses, hospital complexes, military installations, prisons, and some industrial plants. These multipurpose facilities have a single owner and a wide range of utility needs. They have dense loads since the buildings or process loads are located close together. This high density of heating load makes the investment in the heating pipe distribution system attractive. The older systems use steam, and the newer systems commonly use high temperature hot water. Except for some geothermal district heating systems in Idaho, there are no known low temperature hot water systems operating in the United States.

The “old” city-wide systems are problematic; their distribution pipes are nearing the end of their useful life, resulting in steam and condensate leaks, which lower system reliability. (Leaking sections of pipe must be taken out of service before a leak can be repaired.) Since these district heating systems were installed some time ago, they service old buildings

with outdated steam-powered heating, ventilating, and air conditioning (HVAC) systems. The air handling units may contain steam coils, unit heaters may operate using steam, and steam may be distributed throughout the building for local hot water heaters, door heaters, and radiators. Modern buildings would use hot water, natural gas or electricity as the energy source for these space heaters. The cost to upgrade an old building from steam to hot water can be quite expensive—a barrier to converting existing steam district heating systems to hot water.

2.1.2 Systems Operating at U.S. Army Installations in the CONUS

According to the HQ-EIS database, the Army boiler inventory has a total capacity of approximately 30,000 MBtu/hr in central plants that serve three or more buildings. The connected thermal distribution systems have a total length of about 8.8 million feet. Typical plants range in size from 50 to 200 MBtu/hr with an average of about 70 MBtu/hr. Like the city-wide systems, many of the district heating systems found at Army installations are 40 to 60 years old. These older central systems are also experiencing failed insulation and condensate piping, poorly performing boilers, and controls that need updating. This results in energy waste, high maintenance costs, and marginal performance of the building's HVAC and domestic hot water systems. The leaks in the pipes saturates the insulation, which destroys its insulating value and the thermal media flowing in the pipes cools faster. The moisture on the pipes outer surface accelerates the corrosion of that surface and results in a shorter pipe life and more future leaks. Also, major condensate system failures result in high makeup water rates for the boilers leading to water chemistry problems and scaling. Some systems experience 60 to 100 percent makeup rates, which could exceed the installed water treatment system capacity.

Replacement of these piping systems is expensive. Often the repaired pipe lasts only a few years before new leaks recur. This is generally due to poor water chemistry treatment programs. Acidic condensate, oxygen pitting, and intrusion of untreated domestic water at heat exchangers leads to pipe failures and high make up rates at the central plants. This process leads to a downward spiral of system efficiency and life. The distribution systems are located underground along other utility systems. Often their exact location is not known and the effort to uncover them must be done with extreme care to avoid disturbing other utility services (although many leaks

can be located by following the trail of dead grass, melted snow, or miniature geysers rising from the ground).

Most of the older Army systems in the CONUS are either high pressure steam (150 psig) or high temperature water systems, neither of which would be recommended today. They are simply too maintenance intensive and problematical. Their high temperatures and pressures require metal conduit piping, which in direct burial applications is subject to soil corrosion resulting from poor cathodic protection. Remedies such as shallow trenching are expensive to implement, and above ground applications are not desired.

Newer central energy plants tend to be small in size and are built to serve a small group of buildings such as a barracks complex, and to provide both hot and chilled water. These smaller plants started to appear in the 1970s in new barracks complexes and their construction continues today in the current barracks modernization program. There is also a trend towards abandoning central heating plants by installing a natural gas distribution system and smaller boilers in the buildings. This trend may end as natural gas costs increase. Such decentralized systems have much less fuel flexibility than alternative central plants.

2.2 Central District Heating Plants Operating in Europe

District heating systems can be found in most of the larger cities in Europe. Depending on the climate zone, DH is more common in the colder parts of Europe. The density of DH systems decreases as one moves from northern Europe (Scandinavia) to southern Europe. For historic reasons, district heating has a higher residential market share in Central and Eastern European (CEE) countries (approximately 40 percent) than in the former European Union (EU)-15 Member States (10 percent). DH systems are used less extensively in southern Europe, where the climate requires air conditioning rather space heating (Figure 1).

DH is experiencing an upward trend in several EU member states. Meanwhile (according to GEF), in Central and Eastern Europe, the DH share in the residential market is stable, but production in 2003 significantly decreased as compared to 1999. The higher cost to build DH systems, and the introduction and expansion of metering systems, have led to changes

in customer behavior and consequent energy savings. At the same time, the refurbishment and modernization of DH schemes have induced further energy savings. Figure 2 gives an overview of the CHP share of most European countries.

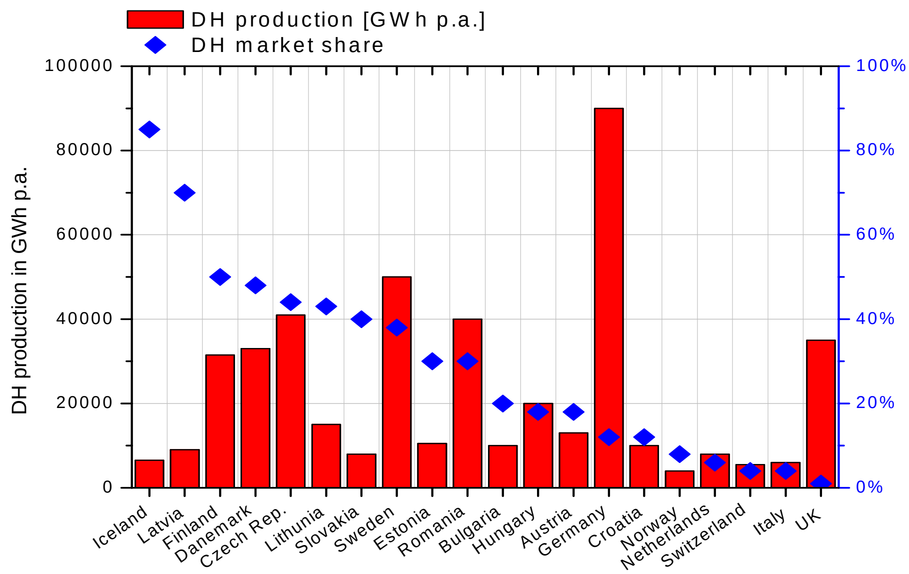


Figure 1. District heating production and residential market share (Source: GEF Ingenieur AG).

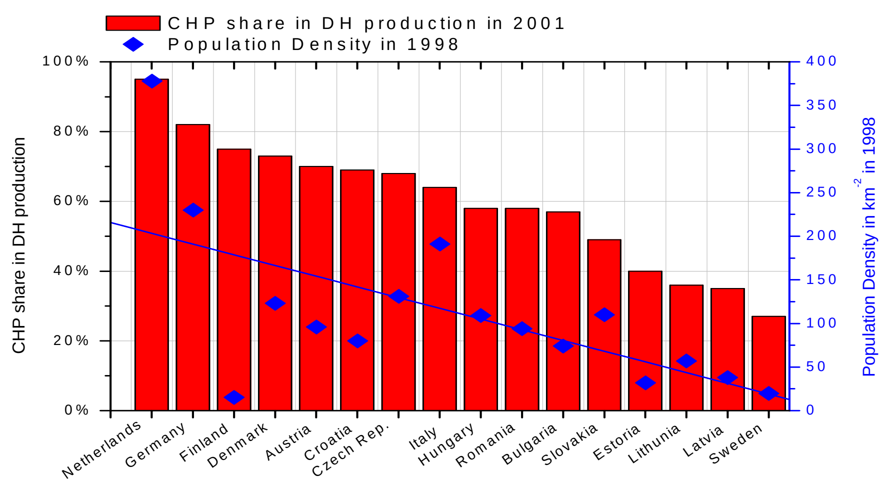


Figure 2. CHP share in DH production (2001) and population density (1998) (Source: GEF Ingenieur AG).

The data shown in Figure 2 suggest that the share of CHP plants is correlated with population density (except in Finland and Italy). The blue line

in Figure 2 is the computed linear regression of the population density, which indicates this trend. The share of CHP in DH production is a function of two facts:

1. A high population density benefits from DH, since first investments for a piping system are quite high (more users can bear the costs) while the O&M is less costly. Countries with a relatively high population density are more likely to have more DH than those with comparable weather conditions and lower population density.
2. DH systems are highly efficient; most (CHP configurations) generate power and heat simultaneously. A high price for electrical power promotes the use of co-generated heat. Since the high price of electricity covers the cost of electrical generation, co-generated heat is very nearly a “free” energy source that utilities can sell at a relatively low price.

However, in Germany CHP is encouraged by law. In 2002, the government implemented a “CHP Modernization Act.” Under this law, operators of CHP plants can obtain an extra reward for electric power produced in a cogeneration process.

In Finland, approximately half the population is served by DH, and approximately three-fourths of the DH is provided by CHP plants. The DH network has a length of 9700 km and the annual growth is in the range of 2 to 3 percent. The heating plants have a capacity of 19,300 MW, and the total heat demand is 15,500 MW, indicating that the system is well configured to meet demand. Appendix D, Section 2 gives more information on DH use in Finland.

In Finland, the cost of DH service is quite reasonable, an average $0.0389 Euro per KWh. The DH energy cost includes a fixed demand charge, which is added to the energy use fee, then marked up by 30 percent for taxes. The cost in the summer is generally half that per unit of energy charged in the winter.

In Eastern Europe, the desire to increase the DH market share may have a political-historical motivation. On its surface, DH technologies seem well matched to economic notions of “centralization” and “market control.” Moreover, Eastern Europe housing architecture, which is characterized by extremely dense blocks of concrete towers that can include hundreds of dwelling units, offers ideal conditions for DH.

2.2.1 U.S. Army Experience with District Heating Systems in Europe

In the late 1970s the U.S. Army in Europe wanted to decrease its operating costs and modernize the heating plants and systems. Utility costs in Europe were twice those in the United States. There were several reasons for the desire to modernize—to increase efficiency, reduce labor and maintenance costs, lower fuel costs, and reduce pollution. Most of the heating systems were coal-fired. After World War II, the U.S. forces occupied installations and barracks complexes that were formerly German Army facilities. Many were built in the late 1930s and some even dated to the U.S. Revolutionary War—having housed the Hessians who came to America to fight in the revolution. The "stairwell" low-rise housing areas in Germany were built by the German government in the 1950s. They had small central heating plants serving several housing buildings. These plants were equipped with hand-fired coke boilers. These boilers were installed to enhance the German economy by providing jobs by creating a market for German coke. The U.S. coal lobby discovered this large use of German and French coal and Congress required that U.S. coal be shipped to Europe to burn in the Army plants. Anthracite coal was used for the coke-fired boilers and high volatile bituminous coal was used in the other coal-fired boilers. In the 1960s the U.S. forces started to convert these boilers to oil firing. The coal lobby soon caught onto this and Congress then forbade the switching from coal to oil. The hand-fired boilers had a thermal efficiency of about 40 to 50 percent and the anthracite had a delivered cost of about $212/ton (1980 dollars). The delivered cost of bituminous coal was about $140/ton. The delivered cost of an MBtu of heat to a housing unit was in the range of 20 dollars at that time.

In an effort to modernize the heating systems and reduce costs the Army embarked on a program to centralize the plants into much larger ones serving an entire housing area or barracks complex (kaserne). Host Nation air pollution regulations required tall stacks and baghouses to reduce and disperse emissions. Many local politicians did not want these large coal plants to be built in their cities as they were also making extensive efforts to reduce air pollution. Fortunately, there was no prohibition to convert to district heat, so this process started in the late 1970s when German cities were expanding their systems. This process snowballed throughout Germany and contracts were signed to convert over 230 installations to district heat with a total demand of about 12,600 MBtu/hr (3,700 MW) of

heating supply capacity. These represent most of the larger U.S. facilities burning coal. The U.S. coal lobby fought very hard to prevent this conversion to district heating. This was resolved by the requirement that Congress be notified of each conversion and be provided with an economic analysis showing cost effectiveness. These cost analyses and contracts were later audited by the USGAO.

At the same time the district heat contracts were being signed, significant building upgrades were also underway throughout the facilities in Germany. This included new windows, heating systems, exterior insulation, and new distribution systems connecting the buildings together. These upgrades combined with modern district heating plants resulted in an overall 50 percent reduction for heating energy for the U.S. facilities in Europe. In some cases, the distribution system was installed by the district heating provider and in other cases the distribution system was installed and owned by the Army. In the later contracts, specific emphasis was placed on getting the DH supplier to building the on base distribution systems. By 1991, the U.S. Army Europe was saving about $100 million per year in utility and maintenance costs due to the heating modernization program. The major coal yard was closed; coal consumption (and associated emissions) dropped 90 percent. District heat purchases by the Army in Germany peaked in 1994 at about 8 TBtus. After that, many facilities in Europe were closed and returned back to the German government. Current district heat consumption in U.S. facilities in Germany is about 6 TBtu at a cost of about $90 million for an overall delivered cost of about $15/MBtu. It should be noted that this is also paying operation and maintenance of distribution systems and any remaining capitalization costs. The German suppliers invested about 1 billion marks in these systems.

The district heating technology applied at the U.S. installations varied from low temperature water (less than 230 °F) to high temperature water (greater than 320 °F). High temperature systems were only used in a few cases where re-boilers were required because the buildings had not converted to hot water heating. Most buildings constructed after 1920 had hot water heating systems. Most of the systems were designed by either the district heating company or the State Construction Office. The Germans preferred medium temperature systems (230 to 320 °F) and these were the dominant design. A few low temperature systems were installed when Danish companies won the design/construct contracts. In the major cities,

conventional district heating systems were either in use or in construction. When this was the case, the U.S. facilities simply connected to the existing system. In some cases, the contracts with the U.S. facilities were enough to promote the construction or expansion of a local district system. For example, the connection of the U.S. facilities in Mannheim and Heidelberg spurred the construction of a 30 kilometer (1 meter diameter) line between Heidelberg and Mannheim and the interconnection of several existing plants in the Heidelberg region.

In smaller locales where no district system existed, the city works or utility built smaller plants on the individual U.S. installations and supplied heat through either a U.S.-owned distribution system or one that they installed, owned, and maintained. The latter became the preferred method of contracting as experience with these systems grew. The U.S. Army put many communities in Germany into the district heating business.

2.2.2 Specific Facility Types in Europe (CHP vs. DH only)

In Europe and especially in Germany, different facility types are common. In most cases, a public utility is owner and operator of a DH system, and often provides all the energy (power, heat, natural gas) and water used by its customers. Sometimes the utility operates the local public transport system as well. A more special facility type is one that provides DH only. This case can be found in both eastern and western European countries. Since natural gas and DH are major competitors, the area served is often divided into concession areas (e.g., for both natural gas and for heat).

A newer type is the “contracting model.” When a township or a industrial company operates a central energy plant with a DH network that is in need of a major upgrade, the existing plant must be refurbished or replaced as well. Since this is quite a costly, either the associated industry or municipality may seek an alternative financing method by advertising a “contracting contract.” In a “contracting contract,” the organization providing the financing operates the modernized DH facility and provides the heat service to the heating customers for several years. In some cases, after the period under contract, the site owner and heat customer may become the owner of the new plant. Another possibility is that the contractor may buy the old plant and DH network for a symbolic amount and both contractor and customer may agree to a long-term contract.

3 Current European District Heating Systems

3.1 Central Energy Plant Issues

As mentioned, there are two different types of Central Energy Plants (CEPs) in Europe: (1) central heat plants and (2) Combined Heat and Power plants (CHP plants). While heat plants are typically connected to one heating system, CHP plants are typically connected to the electric mains and to the heat distribution system.

Note that a plant connected to one DH system may also be connected to different DH networks with different parameters in one common area. For example, the majority of the heating energy in Munich is provided by two major generation sites. These two generators are connected to one DH system, which is separated into five secondary (DH network) loops. Due to customer demands, these five DH networks are operated as secondary distribution systems under different pressure and temperature conditions.

In central Europe, the electric mains tie into the "UCTE" grid. (Union for the Co-ordination of Transmission of Electricity)* (Figure 3). The northern European countries (Sweden, Norway, Finland and the northern part of Denmark) connect to the "Scandinavian-Network." Both major European electricity networks are linked.

The size of a CHP plant is not determined primarily by the electric power demand, but by other boundary conditions that relate more to the size of the DH system. One of the most important boundary parameters is the size of heat sinks at the plant's site. The heat sink for the power plant might be a cooling tower, a river, or a DH system. Thus, the electrical capacity of a CHP or a power plant depends on the share of waste heat (low-pressure steam requiring condensing) that can be cooled, and the share of heat that can be fed into the DH system.

* From the French: "L´Union pour la Coordination de la Production et du Transport de l´Electricité."

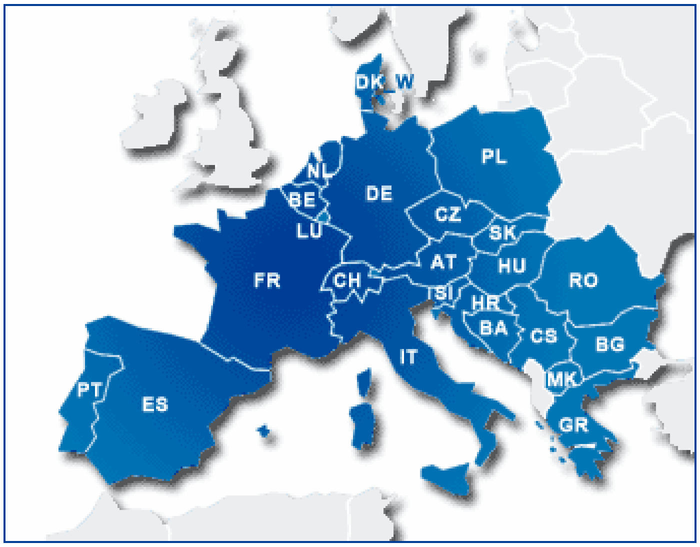


Figure 3. European UCTE system, which it supplies 450 million people with an annual amount of about 2,300 TWh_{el} electric power.

During the winter, when the heat demand is high, power cogeneration is at its highest. During the summer, power cogeneration falls to a minimum. If cooling capacities are available, the additional heat will be cooled. In the spring and autumn, the balance of power cogeneration and power production with condensation depends on the ambient temperature and the related heat demand in the DH system.

In Europe, electric power is traded on a stock market. (The following case does not account for the security of the power supply.) Since power is generated into the mains, a power generation forecast is made to estimate the price that may be charged for electric power in the stock market. Economic forces determine the optimal price for electricity, which effectively subsidizes the price of heat to the customer.

3.1.1 Central Energy Plant Component Size and Efficiency – Example

As previously mentioned, the size of a CEP depends more on the heat demand in the DH systems than on the power demand. Since DH systems use heat plants, the system must balance hydraulic restrictions in the heat distribution system with the need to meet peak load demands. From this standpoint, it is less important to discuss the number and size of boilers than to discuss the balance of heat plants and CHP plants in one DH system is indicated.

The liberalization of the EU energy market has had some important impacts on the heat market. First, customers are able to choose between suppliers for both power and natural gas. Since most municipal utilities provide power, natural gas, and DH, there can be competition between natural gas and DH in one company. Second, distribution is not a problem. Natural gas piping systems are well developed and light fuel oil is commonly available. Thus, the competitive price for these two fuels determines the applicable price for DH.

To finance DH with cogenerated power, the CEP plant should operate at full load (at peak efficiency), which also reduces the time the heating plant must operate. In other words, a CEP plant should operate as a base load plant and supplemental heat plants should be used to meet peak loads and to maintain distribution system hydraulics (the required pressures, pressure differences, flow and return temperatures).

This economic law of DH is derived from the ratio between first investment cost and heat initial cost. Figure 4a shows a time-variation curve of an industrial DH system in 2003. Figure 4b shows the associated load duration curve. The peak load is at 86 MW. This system provides a good example of the economic relationship between first investment and heat initial cost.

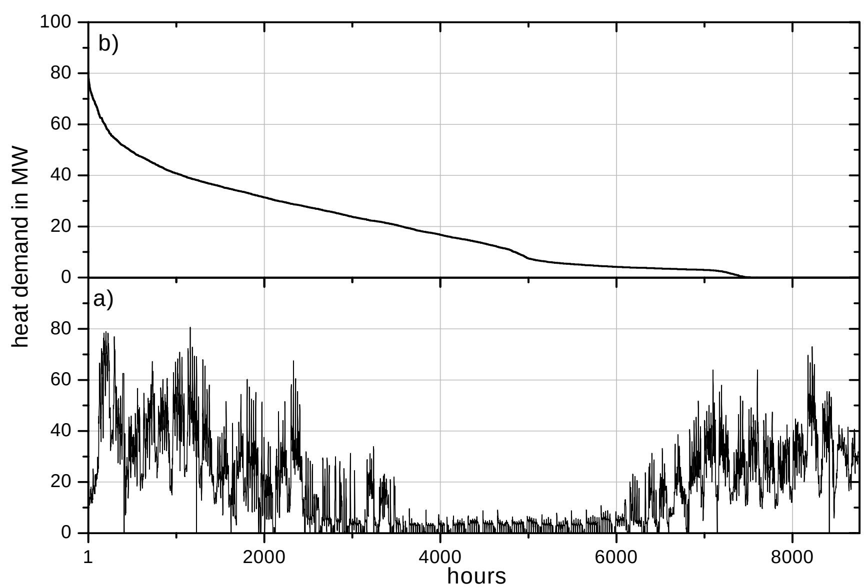


Figure 4. Time-variation curve of an industrial DH system in 2003 (a), and the associated load duration curve (b).

This DH system must supply an annual heat demand of 171,318 MWh_{th}. The system currently operates five boilers with a capacity of 22 MW_{th} each. One 22 MW_{th} boiler has to be replaced due to legal requirements. Thus, two options are under investigation: (1) a replacement of the old boiler by a new one, or (2) the replacement of the new boiler by a CHP gas turbine. In either case, natural gas is the assumed fuel.

In the case of replacement by kind, a new heat boiler with the capacity of 22 MW_{th} is the solution of choice. This boiler must have a load time of 7,742 hours per annum to generate the required energy of 170,318 MWh_{th} per annum With a capacity factor* of 0.8, the burned natural gas will yield 234,187 MWh (network calorific value). Since the industrial site also has an power demand, the total power of 150,941 MWh_{el} per annum must be bought from a utility.

If cogeneration gas turbines are installed, the recommended solution includes two turbines with capacities of 7.5 MW_{el} and 11 MW_{th} each, providing a realistic full load time of about 5,500 hours per annum (Figure 5). The full load time block of the gas turbine shown in Figure 5 is not best suited in this way, since it considers an operation that uses only one turbine. Figure 6 shows the full load time provided by a solution that proposes two turbines of 7.5 MW_{el} capacity including part load operation.

The heat generated with these gas turbines results in 121,000 MWh_{th} per annum, which equals 82,500 MWh_{el} per annum and exacts a fuel demand of 265,980 MWh of natural gas. The capacity factors are 45.5 percent for heat generation and 31 percent for power generation.

Thus, the remaining power demand of 68,441 MWh_{el} must be bought from the utility. Also, the maximum connected load to the grid can be reduced by the capacity of one gas turbine, i.e., 7.5 MW_{el}, because the time-variant load curves for heat and power offers the opportunity to use the generated heat the entire time power is required, i.e., cogeneration of heat and power occurs throughout the year. Shutting down the second gas turbine when there is no heating load will have minimum impact on the operating cost of the facility. One turbine manufacturer states that fewer than 100 turn-

* “Capacity factor” is defined as the annual averaged efficiency of a plant. The capacity factor considers times with no-load operation as well as times with full and partial load.

downs and starting cycles would have no impact on gas turbine maintenance. Table 1 lists data on both heat boiler and gas turbine solutions.

The data from Table 1 indicate that the solution with two gas turbines can save about 1.2 million EUR per year. (Note that taxes, depreciation etc. are not taken into account.) An enhancement to this system would be to install a waste heat booster to optimize the gas turbine cycle and to reduce the load time of the boilers (Figure 6).

Another use of the heating boilers is to maintain proper flow and pressures in the distribution system. In a large-area network with long distances or with significant altitude differences,* heat plants are needed to ensure a secure and failure free operation of the DH system. Parameters including pressure in flow and return pipes, pressure difference at a critical customer, and supply and return temperatures) must be kept within certain limits. A supplemental heat plant can be used to maintain the required values of these parameters.

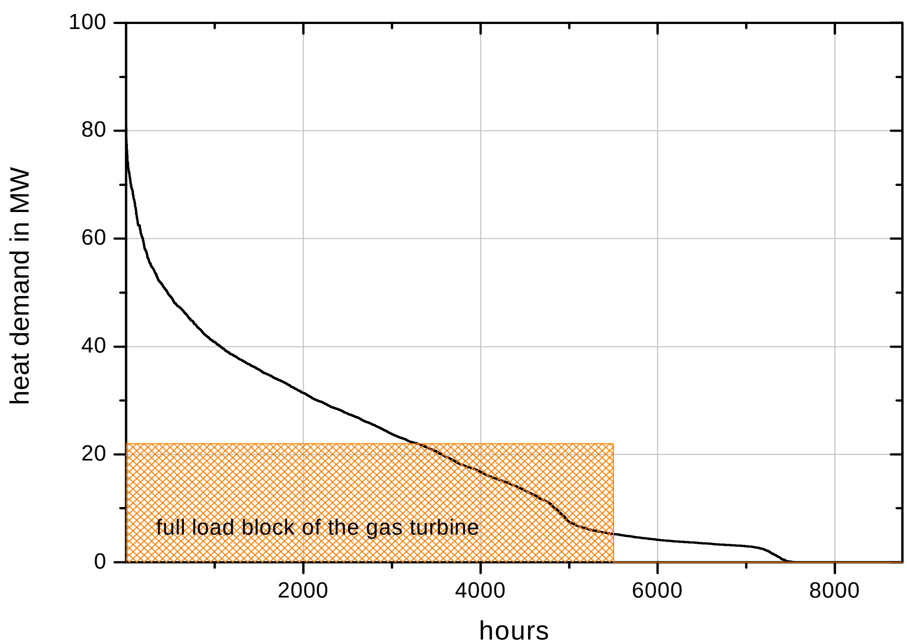


Figure 5. Full load time as a block of the gas turbine solution.

* An altitude change of 10 m (~30 ft). causes a pressure change of 1 atm.

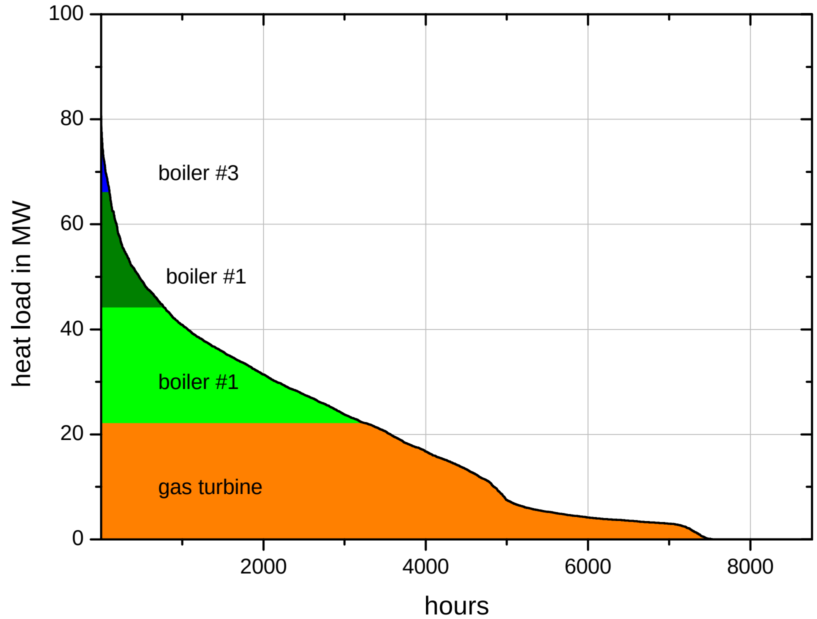


Figure 6. Full load time blocks of the gas turbine solution including the peak load boilers.

Table 1. Comparison of the two possible solutions to replace a capacity of 22 MW_{th} in an exemplary industrial DH system.

Parameter	Gas Turbine 2 × 7.5 MW_{el}; 11 MW_{th}	Heat boiler 22 MW_{th}
Heat demand per annum	170,318	170,318
Power demand	150,941	150,941
Full load time per annum	5,500	7,742
Generated power	82,500 MWh_{el}	–
Generated heat	121,000 MWh_{th}	170,318 MWh_{th}
Fuel (natural gas)	265,980 MWh	234,187 MWh
Specific costs for fuel	30 EUR/MWh	30 EUR/MWh
Total fuel costs	7,979,400 EUR	7,025,610 EUR
Additional power from utility	68,441 MWh_{el}	150,941 MWh_{el}
Specific power costs	68 EUR/MWh	68 EUR/MWh
Total power costs from utility	4,653,988 EUR	10,263,988 EUR
Heat generation in peak load boiler	49,318 MWh_{th}	–
Fuel for peak load boiler (η = 0.8)	67,812 MWh	–
Specific costs for fuel	30 EUR/MWh	–
Total fuel costs	2,034,360 EUR	–

Parameter	Gas Turbine 2 × 7.5 MW_{el}; 11 MW_{th}	Heat boiler 22 MW_{th}
Sum fuel and power	14,667,748 EUR per annum	17,289,598 EUR per annum
First investments	11,500,000 EUR	1,700,000 EUR
Annual capital cost including first invests, O&M, interest etc. For 20 years	1,650,000 EUR per annum	224,000 EUR per annum
Sum fuel, power, capital etc.	16,317,748 EUR per annum	17,513,598 EUR per annum
Savings with gas turbine	1,195,850 EUR per annum	

3.1.2 Hot Water Heating Systems

Appendix A includes a schematic of a hot water system from the CEP to the customer installation. System elements are numbered from (1) to (12). The important elements are:

1. *Generation, CEP*
   The schematic drawing shows a simple heat plant with three dual fuel boilers. In this case, all three boilers can be fired with natural gas or fuel oil. This boilers could be replaced by any type of CEP, e.g., biomass-fired CHP plants, gas turbines with heat recovery, steam to hot water transformer station, etc.
2. *Water Treatment*
   The water treatment for the DH system is shown. To avoid corrosion and fouling it is necessary to have water softening. Chemical water treatment is standard operation in these facilities. This facility will remove the detached lime fraction in the feed water and reduce the lime fouling in the interior of the pipes. More advanced water treatment systems, e.g., complete demineralization facilities, are recommended in case of aggressive untreated water qualities. In Europe a cost of 5 EUR/1000 L of crude water for water chemical treatment is common.
3. *Pressure Maintenance*
   The pressure maintenance, shown in part (3) of the schematic, ensures an almost constant pressure in the facility, related to the present flow and return temperatures, which are adjusted according to the ambient temperature. By increasing supply water temperatures caused by lower ambient temperatures, the volume of the hot water in the closed system increases. Hence, the pressure inside the pipes located in the facility will increase. To avoid this pressure increase, the motor driven valve (3a) opens and channels the excess water volume from the piping system into the expansion tanks. In case of lower flow temperatures in the DH system, i.e., in case of lower ambient temperatures, e.g., through

the summer or in the night, the feed-water pump again channels the stored water from the expansion tank into the piping system. To balance water losses, a minimum of treated water is stored in the expansion tanks via the additional fitting shown in (2a).

4. *Sequenced Actuation Boiler*
   The consumed heat energy in the entire system (all customers connected to the system) is measured with a heat-meter. In case of load alternations in the hot water system, the boilers (1) are switched on or off via the motor-driven valve (1a).
5. *Control Loop of the DH Network*
   The boilers operate at a constant temperature of 130 °C. Therefore it is necessary to implement a control command variable *ambient temperature*. This control unit adjusts the supply water temperature to the ambient temperature and to the assumed heat demand of the customers connected to the DH system. The lowering of the supply water temperature offers the opportunity to reduce transmission heat losses of the entire DH system. The schematic in Appendix A shows that the bypass valve (5a) opens as the ambient temperature rises to 0 °C. This allows some of the return water to mix with the supply water so that the proper supply water temperature is attained. The lowest supply water temperature is 80 °C. This lower limit of 80 °C depends on the required demand for space heating and domestic hot water preparation. In other words, this flow temperature ensures the security of heat supply to the customers (5b).
6. *Frequency Converter*
   The network pumps are operated via a frequency converter. This control command module is a critical part (6a) of the facility, which optimizes the rotational frequency of the pump (6b), greatly reducing the power requirements of the network pumps.
7. *DH Network*
   There are many options for the installation of DH piping systems:
   a. Above ground level piping
   b. Steel pipes with or without insulation in ducts or dome-shaped ducts
   c. Steel-jacked pipes with vacuum between the pipes in trenches
   d. Pre-insulated bounded pipes with steel medium pipes (plastic-jacket pipes) in trenches
   e. Pre-insulated bounded pipes with plastic medium pipes (flex-pipe) in trenches.

For the past 20 years, one of the most flexible and common types of piping system is the pre-insulated bounded pipe. These pipes consist of a steel medium pipe and a plastic (i.e., polyethylene) jacket pipe. The insulation between the two pipes is made from a polyurethane (PUR) heat insulation foam. The pipes are pre-insulated in the factory and the PUR foam is a rigid material that bonds the outer jacket with the inter medium pipe. Figure 7 shows a unused pipe on the left hand side and, on the right hand side, a 30-year old pipe used in a DH system with a variable flow temperature. The unused pipe is equipped with a leak detection system, indicated by the two wires seen on the far end of the pipe.

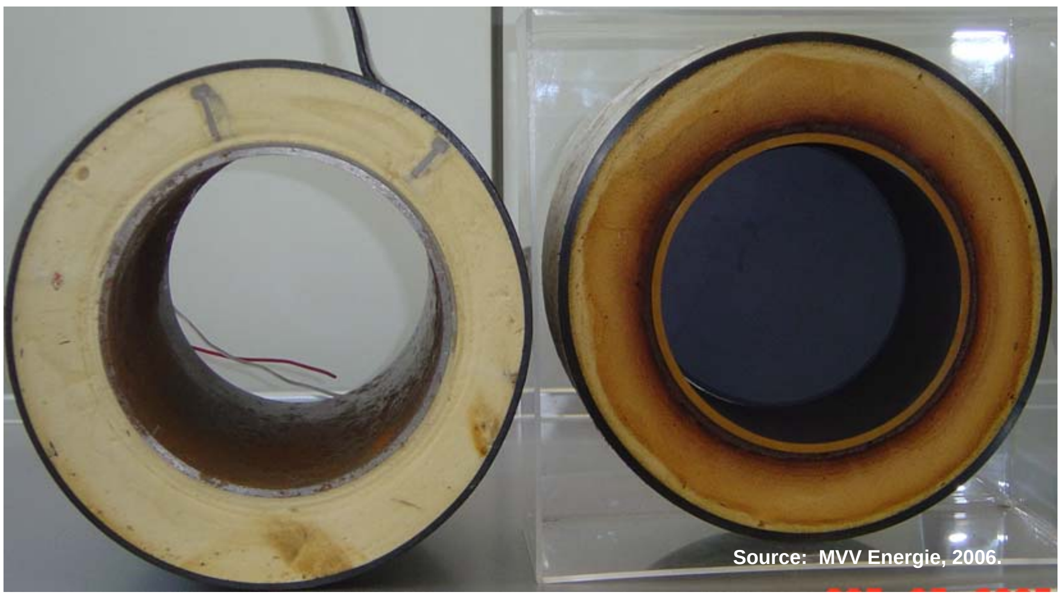


Figure 7. Photo of pre-insulated bounded pipes (pipe on the left is unused and is equipped with a leak detection system; pipe on the right was in use for about 30 years in a DH system with sliding flow temperatures [about 80 °C/130 °C]).

The most important limitation of the pipe is its maximum temperature restriction of 140 °C, which minimizes the aging of the PUR foam caused by exposure to the high temperatures. Negative effects of the pipe aging are reduced shearing resistance of the pipes, which reduces the bonding to the medium pipe and reduced heat insulation. The most important constituent parts of a pre-insulated pipe are:

1. Medium pipe made from steel
2. Bonding insulation made from PUR foam including a leak detection systems
3. Jacket pipe made from polyethylene (PE).

The pipes are buried in frost-free depth in an open trench (Figure 8). After the laying of the pipe with a length of some 5 to 10 m, the single pipes are connected through welding. Those weld joins are tested with radiation and evacuation tests. Afterwards, the PE jacket pipes are connected with shrinking bushings. Finally, the space between the medium pipe and bushings is foamed in place. Figure 9 shows different precast fittings, elbows and branches. Finally, the trench is filled with sand and compressed to bury the pipes. When the pipes are completely buried, the trench is further filled and prepared for the desired surface, which may be a street, pathway or grassland.

Figure 8. Trench/canal for a buried pre-insulated pipe.

Figure 9. Pre-cast fittings and elbows of pre-insulated bounded pipes.

3.1.3 Customer Interface (First Version)

The main parts of the customer interface are:

1. DH control for the secondary side (10a).
2. Control valve (10b)
3. Differential pressure control, flow rate control (10c)
4. Heat meter (10d)
5. Plate heat exchanger (10e).

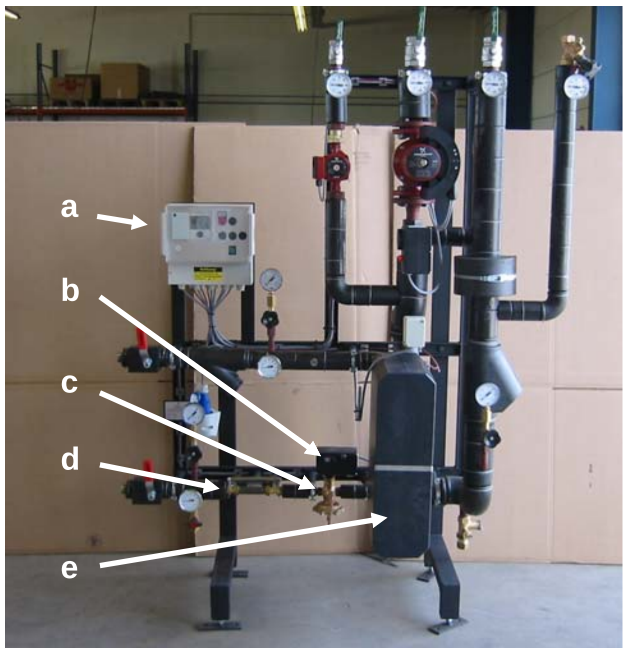


Figure 10. Photo of a modern, state of the art DH compact station.

In state-of-the-art systems all these components of the building interface or customer interface installation are packaged into an assembled unit called a “compact station” (Figure 10).

Both the DH control for the secondary side (10a) and the control valve (10b) regulate the secondary system flow according to the ambient temperature. Furthermore, the control valve is used to program a time dependant adjustment, e.g., the day/night shift, the so called night-time heating reduction.

The differential pressure control, flow rate control (10c), is used to control the flow rate. Therefore, a certain flow rate limitation is fixed while the differential pressure is variable. When differential pressure increases, the

controller shuts according to its setpoint; similarly when differential pressure decreases, the controller opens.

The heat meter (10d) is used both for billing and to control the flow rate. In most cases, the utility owns the heat meter while the customer owns the compact station.

The plate heat exchanger (10e) is used to decouple the primary DH distribution system from the secondary building side. This is important since the secondary building piping cannot bear up the relative high temperatures and pressures of the primary DH side.

3.1.4 Space Heating System (Secondary Loop)

The space heating system shown in Appendix A can handle supply radiators as well as air heating systems. An “admix control” reduces the flow temperature in the secondary loop according to the ambient temperature. This is done by the DH control unit for the secondary loop (8e). Again, the secondary loop can handle different control programs, e.g., for weekend or nighttime heating reduction.

3.1.5 Domestic Hot Water Preparation

Domestic hot water preparation is also an “admix” operation controlled by the DH control unit for the secondary loop (8e). In this loop, the lowest temperature is limited by hygienic conditions. Thus, the lowest flow temperature in the DH system is limited to 70 °C since the domestic hot water must have a temperature higher than 60 °C. The flow temperature must periodically, be raised to 80 °C to boost the domestic hot water to 70 °C (the required temperature to kill legionella) for thermal disinfection.

3.1.6 Customer Interface Installation (Second Version)

In the second version of the DH building interface, the space heating system is separated from the domestic hot water preparation. The domestic hot water tank is directly connected to the primary DH loop. Thus, the regulation of the secondary heating loop does not depend on the DH system; it is independent, and both loops operate independently. These separated space heating and domestic hot water preparation systems are common in facilities with large domestic hot water demand, e.g., in hospitals

or hotels. The loop in-between (11a) the heat exchangers ensures a hydraulic decoupling of the DH water loop from the domestic hot water loop to prevent contamination of the potable water with treated DH water.

3.1.7 Domestic Hot Water Preparation

The control and operation of this directly coupled domestic hot water preparation equals the system described above (section 3.1.5).

3.2 Examples DH Systems in Germany

3.2.1 Mannheim Hot Water DH System

A good example of a hot water DH system is located in Manheim, Germany, which is the second largest city in the federal state of Baden-Württemberg with some 320,000 inhabitants. Manheim is a heavily industrialized city on the banks of Rhine River. The district heating system of Mannheim has 11,800 customers located in an area of approximately 40 square km. Included in the customer base are facilities used by U.S. Army Garrisons. Appendix B discusses this system in detail. The main heating source for the DH system is the CHP plant Großkraftwerk Mannheim (GKM) whose primary purpose is electrical power generation. The total electrical power generation capacity of this plant is 2,100 MWel. Steam is extracted from two backpressure-extraction turbines for the DH system. Two additional steam-water heat exchangers cover peak consumption. Figure 11 shows a schematic overview of the GKM plant.

Two peak heating plants are used when necessary. GKM sells heat energy to MVV Energie AG Company, the municipal utility serving Mannheim. MVV Energie is the owner of the connected district heating (DH) network and distributes and sells the heat energy inside the city. The GKM plant burns coal and the peaking heating plants are fired with light oil.

The peak demand on the heating plants is 1,000 MWth. and the annual consumption is 2,700,000 MWh. The total connected heating load is 2,135 MWth. The supply pressure is 9.8 bar (142 psi, mean pressure above atmospheric level [gauge pressure]). The pressure in the return pipe at the power plant's inlet is 0.5 bar (7 psi).

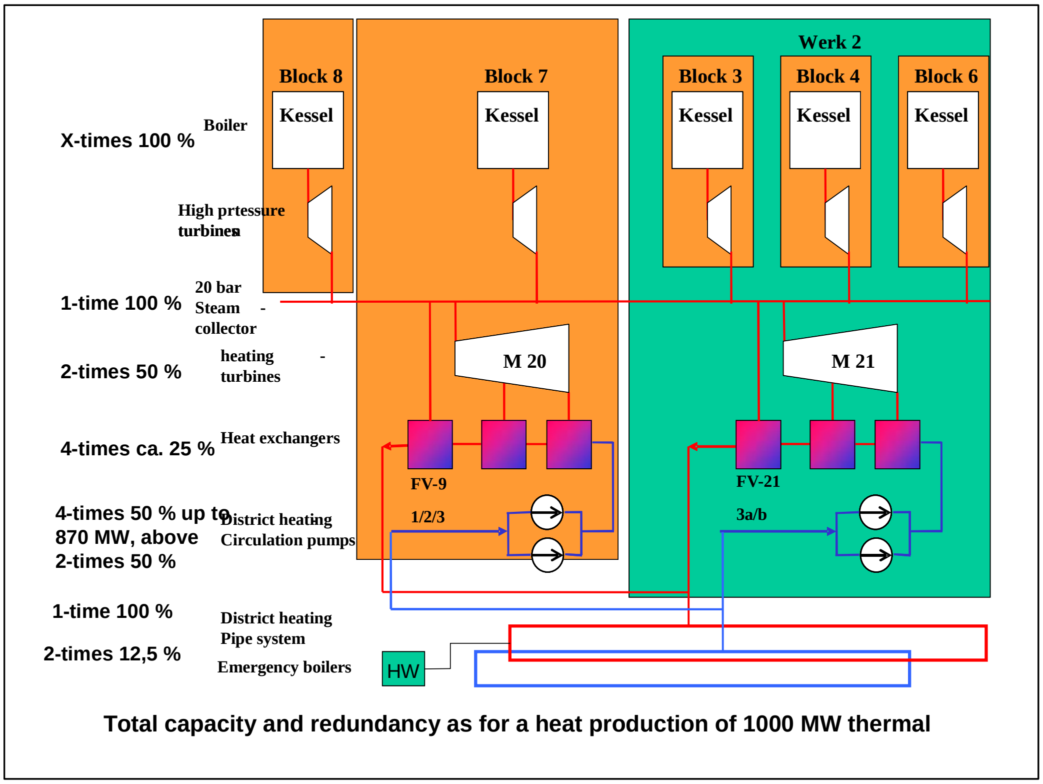


Figure 11. Co-generation of heat and power at Mannheim's large CHP plant.

The supply temperature varies between 90 °C (194 °F) in summer and 130 °C (266 °F) during winter depending on outdoor temperature. The temperature drop of the hot water is approximately 0.4 °K/km pipeline length. Thus the temperature drop from the central heating plant to the last customer connected to the network is in the range of 1–6 °K.

The Mannheim district heating network is a meshed dual-pipe high-temperature grid with an overall pipeline length of 516 km and an average diameter of DN 150. The following pipe-laying technologies are applied:

- 423 km polyurethane (PUR) pre-insulated plastic jacket pipelines
- 56 km pipelines above ground level or in the basement of buildings
- 20 km steel jacket pipes
- 10 km hooded channel
- 7 km thermo-concrete covered pipes.

MVV Energie uses PUR pre-insulated plastic jacket type pipe for most new DH piping and that being replaced. In addition to excellent insulating values this type of buried pipe does not require anchors for expansion and

contraction. The surrounding earth serves as an anchor for the shear stress arising from different temperatures. The PUR insulation is vary hard and transmits pipe forces to the outer jacket.

The insulation used for the pre-insulated pipes is a class 1 insulation thickness. The overhead/basement pipelines, pipes in hooded channels, and the steel insulated pipes are insulated with mineral wool. In the thermo-concrete laying system the insulation consists of gas-aerated concrete, which is situated around the steel medium pipes.

The average age of the DH piping is 20 years. (The first pipes were installed in 1959 in hooded channels.) The PUR pre-insulated plastic jacket type pipe was first used in 1968. Maintenance costs for detection and repair of leaks, replacement of substation components, and repair of inspection chambers are approximately 5 million EURO per year.

3.2.2 Kiel Steam DH System

This section discusses the first of two steam DH systems, located in the city of Kiel, Germany, and its conversion to hot water

The steam DH system in Kiel was installed in 1905. Since the 1960s, hot water has begun to replace steam as the heating medium. Today more than 60,000 apartments, as well as many public buildings, including department stores, administrative and commercial buildings, and the university and hospitals are connected to the district heating network. At present, Kiel is supplied with heat from a total of six heat and/or power stations (Table 2).

The largest of these plants, the joint venture power generating plant on Kiel's east bank, produces more than 60 percent of heat energy for the district heating system. Appendix B (Section 2) discusses the Kiel DH system in detail.

Kiel's public utility works has been converting district heating from steam to hot water in the inner city area since 2002. Over the next few years, the company intends to invest more than 30 million Euros to make its district heating network even more cost-effective and to carry out state-of-the-art

upgrades. From 2001 to 2005, the share of customers supplied with district heating from steam fell from ~35 percent to less than 25 percent.

Table 2. Heat sources of Kiel's district heating steam network.

No.	Name	Function	Total capacity
1	Heating plant North	Peak and reserve plant	180 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)
2	Heat and power plant Humboldtstrasse	Second power plant in Kiel	28 MW_{el}; 176 MW_{th} at 130 °C / 80 °C (266 °F/ 176 °F)
3	Heating Plant West	Peak and Reserve Plant	41.8 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)
4	Waste Incineration plant (Heating plant South)	—	~60 MW_{th}
5	Joint venture power generating plant	Joint venture of E.ON (national-wide energy supplier) and Kiel department of works	320 MW_{el} (largest power plant in Kiel, 50% electr. for E.ON, 50% for Kiel dep. of works), 295 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)
6	Heating plant East	Peak and reserve plant	60 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)

A total of 1571 apartment buildings and a number of other industrial and public buildings are still served by the steam DH system. The total connected load is 278 MW_{th}. The Two heating stations with a capacity of176 MW_{th} and 60 MW_{th} provide the needed steam, which has a peak demand of approximately 100 MW_{th}. The smaller boiler is fueled by waste incineration, and the other boiler by natural gas and fuel oil. In these plants, high pressure steam at 38 bar is run through back pressure turbines before feeding the steam DH network.

During the nonheating season (April through October), the high pressure steam turbines are not used. Power is generated by the gas turbines and the waste incineration plant. The quantity of electrical power generation is based on the heat demand. Surplus heat energy is transferred to the hot water heating networks. A forecast of the heat load is made daily and the corresponding electrical power is sold to the electrical grid.

Pipe Distribution System

More than 125 kilometers of steam and condensate pipe is installed in hooded channels or is buried, either metal jacketed or directly in the surrounding ground. Appendix B (Section 2A) profiles this piping system by

size. The insulation materials used are mineral fiber or gas-aerated concrete. When pipes need replacement, steel jacketed pipe is used with an insulation of rock wool (e.g., 5 to 6 cm for pipes of 80–100 mm, 10 cm for pipes of 300–400 mm diameter). The condensate pipe is not insulated.

The average supply temperature is 160 °C (320 °F) and varies between 150 °C and 180 °C (302 °F and 356 °F). The maximum pressure is 2.5 bars. The returning condensate has a temperature about 55 °C (131 °F). There is also a high pressure steam service to a hospital, which is at 10.5 bar ort 190 °C: (374 °F). This service will end in the summer 2006 with a switch to hot water supply.

The steam enters the piping system with a 40 °C superheat to assure the last customer receives steam at 160 °C. Thus there is a temperature drop of 40 °C in the supply piping system. The agreement with the steam customers is to provide 160 °C. steam even if the demand does not warrant it. For customers on the hot water network, 70 °C (158 °F) must be maintained. (This results in a significant saving in heat to DH supplier.)

The steam piping system has been in use up to 60 years and there is an aggressive program to switch to hot water piping. The annual maintenance is therefore done with a minimum level of effort; less than $500,000 EURO are spent per year. Pipe leaks continue to be a problem. Table 3 lists the leakage history since 1998. After the system is shut down to fix a leak it takes 20 to 30 minutes for the most remote customer to have heat again. With the hot water system this time period can be as long as 6 to 8 hours.

Table 3. Leak history in the pipeline systems in Kiel.

Parameter	Year						
	1998	1999	2000	2001	2002	2003	2004
Steam network							
High pressure	17	10	8	11	9	13	10
Low pressure	0	0	0	0	0	0	0
Number of leakages	17	10	8	11	9	13	10
Hot water							
Mettenhof	2	0	6	1	7	3	5
North/South	26	8	17	22	16	20	21
East	10	6	0	4	3	1	2
Island network	1	0	0	0	0	1	1
Number of leakages	39	14	23	27	26	25	29
Total	56	24	31	38	35	38	39

Customer Interface

All customers have hot water systems in their buildings; therefore, the customer interface is a steam to hot water heat exchanger. The rate of condensate flow is measured for billing purposes. The customers at times have problems with the heat exchangers due to corrosion.

3.2.3 Ulm Steam DH System

This section discusses the second steam DH system, located in the city of Ulm, Germany, and its conversion to hot water. This section describes the feasibility study for converting a steam-based DH system into a modern sliding temperature hot water DH system.

Analysis of the Present Situation Steam System

The analysis of the district heating in Ulm requires a general overview of the city and the district heating supply system adopted there. Figure 12 shows the area serviced area in Ulm/Neu-Ulm, which divides FUG (Former Energieversorgungr Schwaben AG) and municipal utility Ulm/Neu-Ulm (SWU). District heating in Ulm city area is operated by FUG; SWU operates the district heating in the region Neu-Ulm.

Figure 12 shows the steam networks in red; they are not, however seen as independent from the heat water networks, which are represented in blue. A schematic representation of the connection between networks is shown in Figure 13, in which the steam networks are drawn in red.

The illustrations make clear the connection between the individual nets and the production plants that tie into those connecting elements. The following sections will describe the situation in Ulm in detail.

Central Energy Plants

In Figure 13, the CHP plant (HKW) Magirusstrasse is the most important production unit, with six boiler plants presently installed. Table 4 lists the capacities and fuels of the boiler plants.

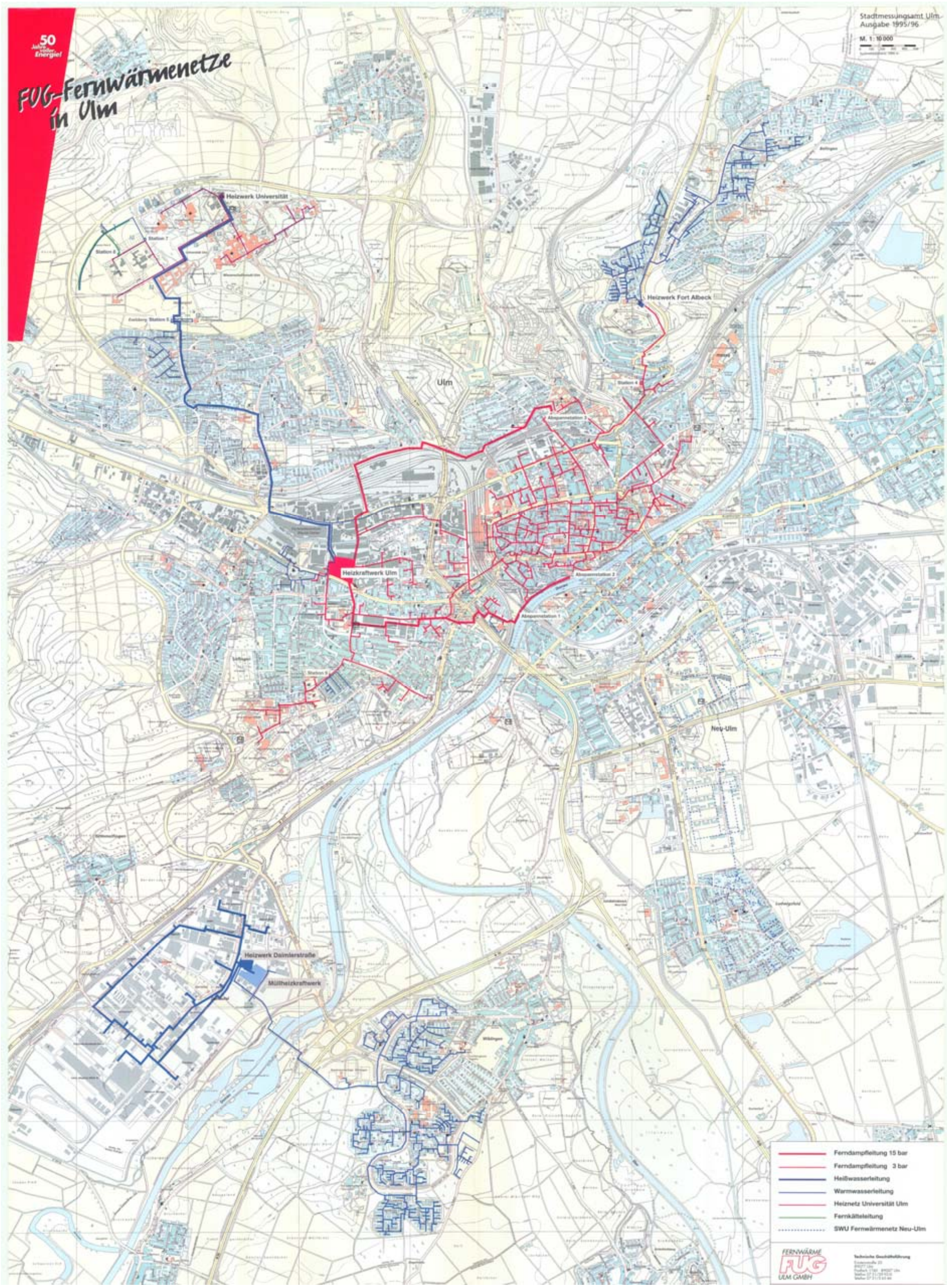


Figure 12. The cities Ulm and Neu-Ulm and the DH systems of FUG and SWU.

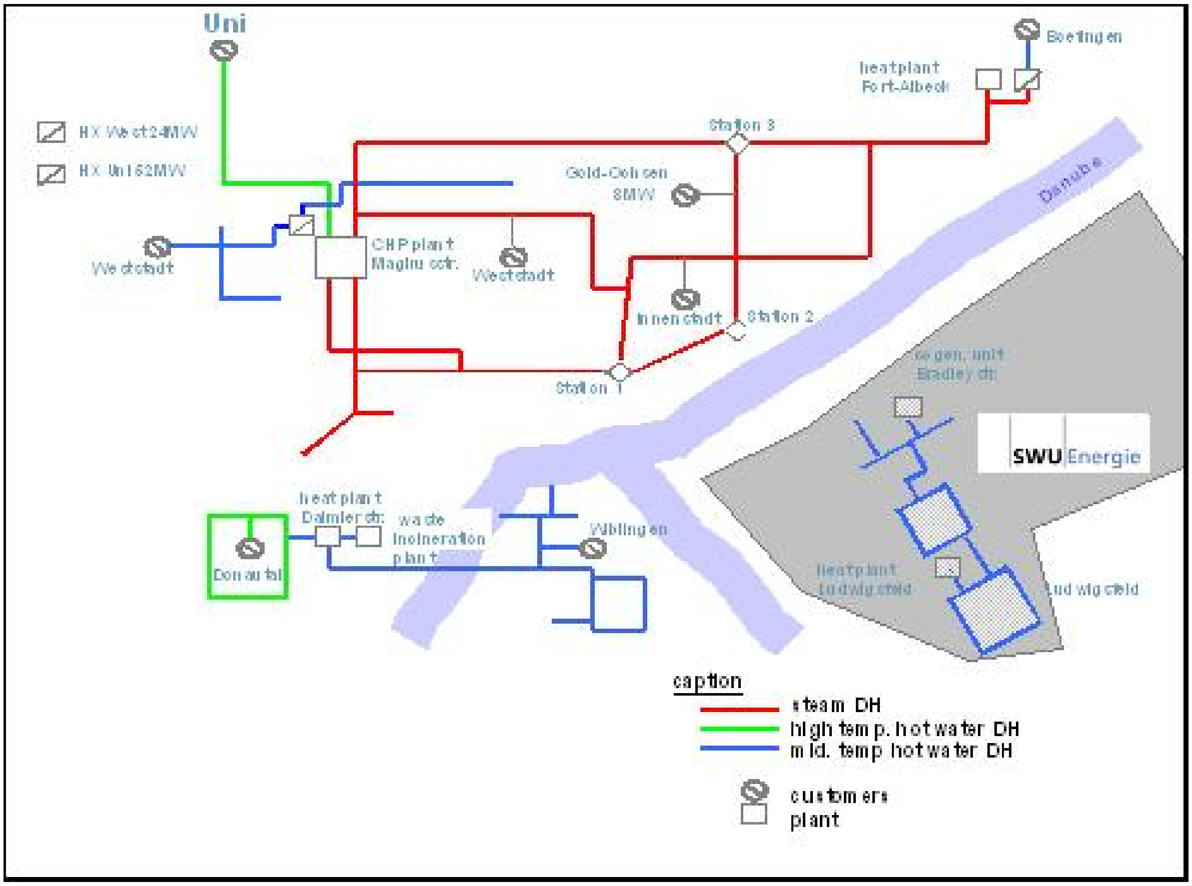


Figure 13. Schematic overview of the networks and CEPs.

HKW Magirusstrasse is a bus atm power station. Boilers 1, 3, 4, 5 and 6 can feed common steam header and drive turbines 1, 3, 6, and 8 in the KWK enterprise. Boiler 7 is a Biomass–HKW brought into operation in 2003 that feeds an independent Turbine (7). Altogether, the unit HKW Magirusstrasse yields a KWK thermal output of 218 MW. The heat extraction takes place predominantly on a high temperature level (steam network and university line). Figure 13 also shows that the system allows heat removal is any direction. The current problem at Magisrusstraße is the limited cooling for the condensation operation of the steam turbines. The only water available for cooling is from the Blue River, which can provide only a limited amount. This reduces the hours of use of the KWK plant and thus its economy of scale.

Table 4. Overview on production units at HKW Magirusstraße.

Unit	Capacity * [MW]	Built Year	Fuel(s)
Boiler 1	58	1969	Gas/HEL
Boiler 3	52	1949	Coal
Boiler 4	52	1949	Coal
Boiler 5	65	1956	Coal
Boiler 6	91	1978	Gas/HEL
Boiler 7	60	2003	Wood
Turbine 1	2 MWel	1950	
Turbine 3	15.55 MWel	1992	
Turbine 6	8.85 MWel	1956	
Turbine 8	0.48 MWel	1954	
Turbine 7	8.6 MWel	2003	
*Thermal capacity of boilers			

Figure 13 also shows the heating stations at Fort Albeck and the University. Table 5 lists the capacities and fuels of these boiler plants. These heating stations are primarily meant for the security (back-up) and peak loads. These three peaking boilers can relieve the lines and the HKW Magirusstrasse at peak periods. In addition, the heating station Fort Albeck can be connected through step-down substation 3 into the steam network and into the HKW Magirusstrasse.

Table 6 lists the design values of the production plants at Heating Station Daimlerstrasse. These plants serve the supply of two nets -Donautal and Wiblingen. Figure 14 shows the first schematic overview of the networks depicted in Figure 13 that quantifies system connections. Figure 14 shows the importance of the HKW Magirusstrasse's central position to the long-distance heat supply in Ulm.

Table 5. Overview on the production units at University and Fort Albeck.

Units	Capacity [MW]	Built Year	Fuel(s)
Uni-Boiler 3	23.4	1976	Gas/HEL
Uni-Boiler 4	34.8	1976	Gas/HEL
Boiler Fort Albeck	18		HEL

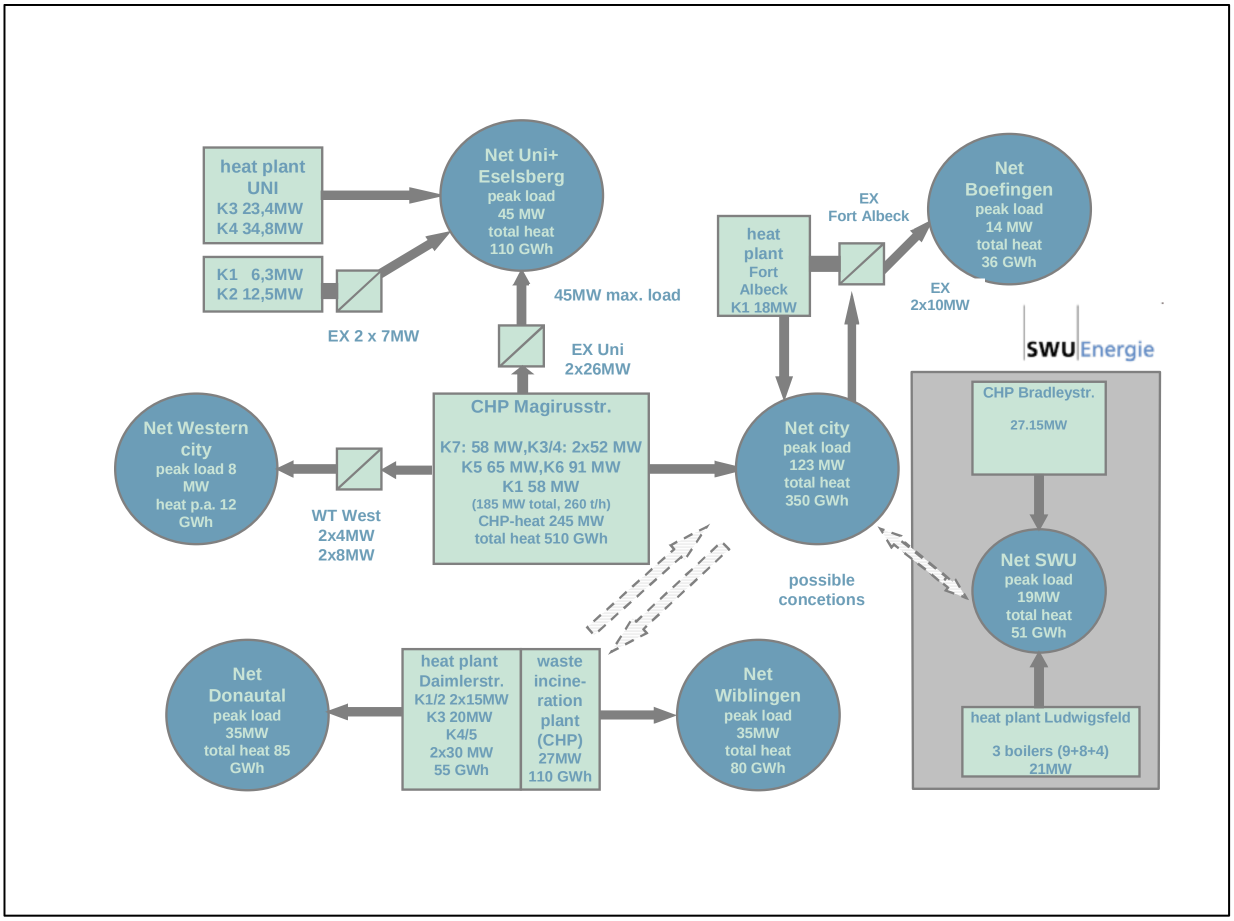


Figure 14. Quantitative System connections between the CEPs and the DH system parts including the most important values (Note: CEPs are shown as right angles; DH networks are shown as circles; boilers 1 and 2 in the heat plant Uni have been decommissioned since 2005).

Table 6. Overview of the production units in Heating Station Donautal including waste-fueled power station.

Unit	Capacity [MW]	Built Year	Fuel(s)
Boiler 1	15	1967	Gas/HEL
Boiler 2	15	1967	Gas/HEL
Boiler 3	20.0	2004	Gas/HEL
Boiler 4	30	1977	Gas/HEL
Boiler 5	30	1977	Gas/HEL
MHKW	27*		Müll
*District Heating pipeline.			

Network

This section summarizes the present situation in the steam system without detailing the hot water systems. Figure 15 quantifies the most important characteristic of the individual networks (yearly work and maximum load).

The steam network in the Ulm city center has grown since 1950 to a current route length of approximately 54.9 km. The starting point is closely connected with the today's location HKW Magirusstrasse. Figure 16 shows the development of the steam pipes in the steam network in 5-year steps, separated according to nominal sizes. Figure 16 clearly shows that the main structure of the network took place over 10 km in 5 years between 1955 and 1964 following the initial phase between 1950 and 1954.

The two 5-year cycles before 1974 clearly show a weak, but nevertheless, considerable development activity. This development can be characterized as "considerable" because if involves large nominal sizes, which indicate fundamental network development (laying the so called "Ports"). In spite of the apparent attenuation in development, one must consider that, for each 5-year step, a small development length of slightly more than 5 km has taken place. Another important development phase can be seen between 1980 and 1984,when the development length exceeded 5 km in 5 years.

According to information from FUG, the development phase after 2000 is primarily due to a line exchange in the range of the new roads, which explains the building from DN250 to DN300 pipelines with a length of approximately 1 km.

Figure 17 shows the development of the condensate pipelines. As expected, the timed operation shows similar development, but also shows large differences in the nominal sizes. The nominal sizes of the large transportation lines are unlike those of the house service connection lines. Only a few kilometers of the transportation lines are condensate lines larger than DN100. These, along with the house service connection lines, outsize the nominal sizes between DN25 and DN32. This trend appears constantly during the entire period since 1950.

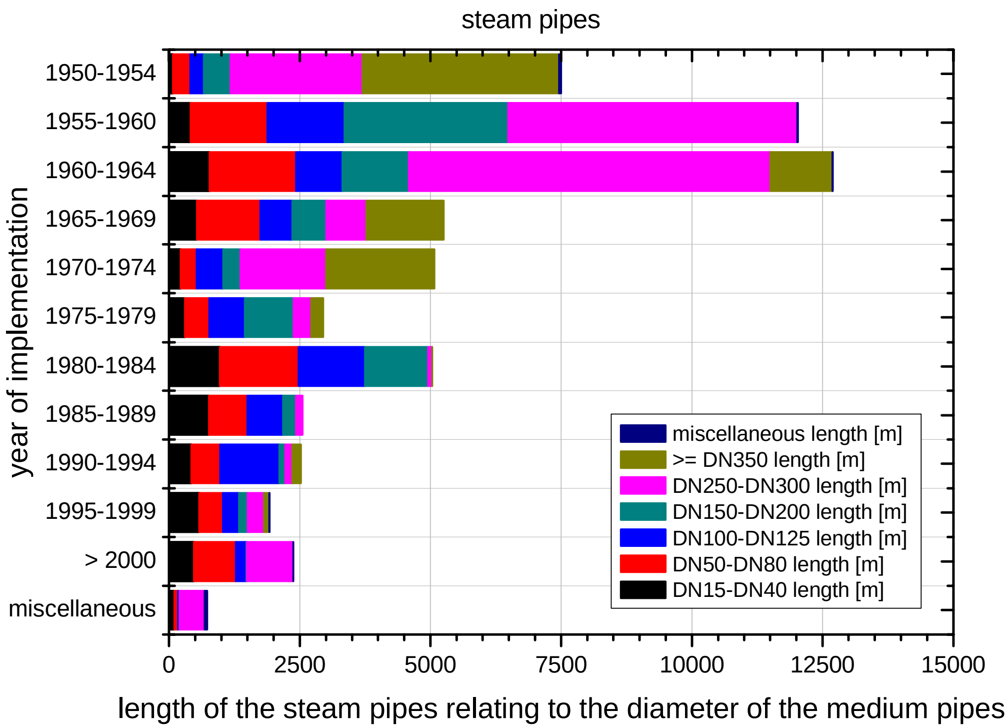


Figure 15. Length distribution of the steam pipes against nominal size and year of implementation.

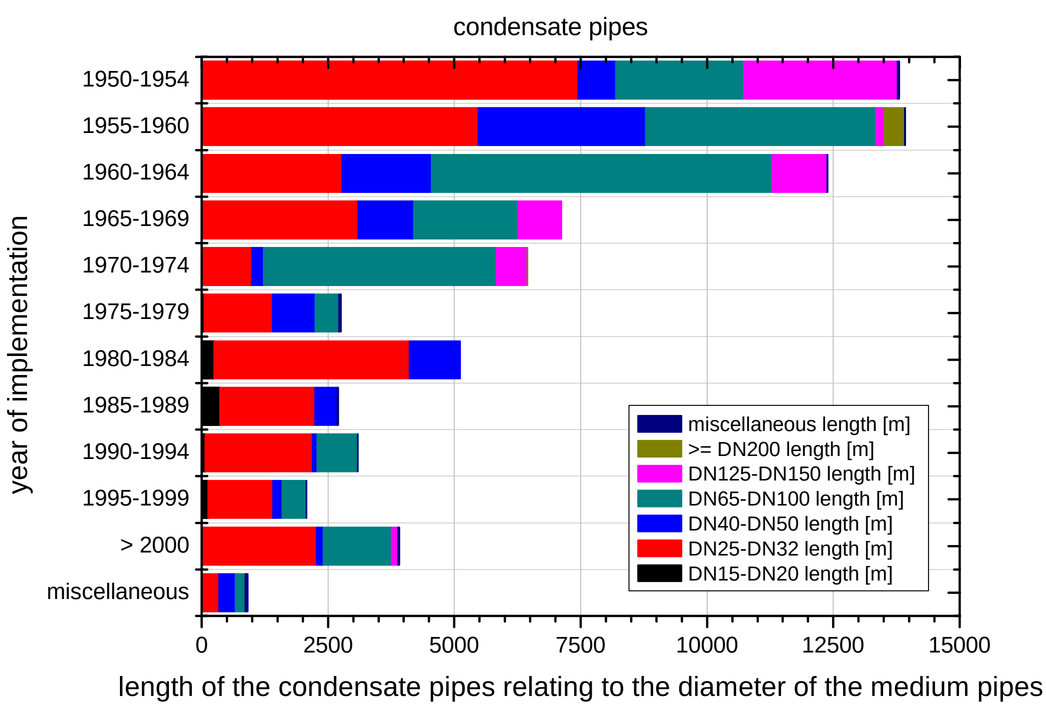


Figure 16. Length distribution of the condensate pipes against nominal size and year of implementation.

Besides the issue of network development, several concerns require attention: possible conversion of the steam network to hot water, the nominal pressure level, the number of ducts, and the distances between bearings. From FUG's documents and process sheets indicate that approximately 1,150 ducts are to be found in the steam network. The valves and wall thickness of the piping are according to FUG's statements, designed for the compression phase PN16. (FUG's database confirms this.) Only 44 (less than 2 percent) of the 2,279 compressors listed are PN10-compressors. This means that PN16-laying can proceed. Table 7 lists data from a basic FUG worksheet that shows distances between bearings and, respectively, spans for steam and condensate lines.

On 17 March 2005, an onsite investigation of important line sections was made to examine the further serviceability of existing lines, and also to examine existing routes to ascertain if newly laid pipes would be required. For the so called Südtrasse, further use of the accessible channel for the pipe line from HKW Magirusstraße along the Moltekestraße, parallel to Wörthstraße over the EADS-Gelände and the Ehinger Anlagen up to Oberen Donaubastion was, to a large extent, excluded. In the region Westplatz, Söflinger Straße, the channel was partially in bad condition such that existing pipe-laying was hindered.

The moats along the Olgastraße and the Heimstraße up to Zundeltor were also examined. These moats occupy a partly accessible subway that lies under monumental protection. It is assumed that part of the surface water (possibly by road intakes) flows into the moat, which passes on into the Donau. The moat floods several times a year, and the bed of the moat is very dirty. The existing steam and condensate lines are in a partly bad condition. Axial expansion joints are used to expand the steam pipe. New pipe was laid the existing lines were being disassembled. New hot water lines must be provided with a stabilizer to offset the danger of flooding. However, the moat required special treatment to accommodate new pipelines. The existing lines were disassembled because the existing lines have different turning radii from the installed lines; the new installation required that the new lines be placed on opposite sides of the mote.

Table 7. Allowed spans for steam and condensate lines.

Nominal Diameters																Width Between Two Supports (m)	
25 — 150			200 — 450														
Steam	ED x WT*	Condensate	a	b	C	d	e	f	g	H	H+c	h	i	k	l	Steam	Condensate
25	33.7 x 2.6	25	650	150	—	300	240	65	455	116	—	116	40	173	65	1.8	2.6
32	42.4 x 2.6	25	650	150	—	300	240	65	455	120	—	116	40	181	60	2.1	2.6
40	48.3 x 2.6	25	850	150	—	450	350	80	580	133	—	116	50	207	120	2.5	2.6
50	60.3 x 2.9	25	850	150	—	450	350	80	580	139	—	116	60	229	105	3.2	2.6
65	76.1 x 2.9	25	850	150	—	450	350	80	580	198	—	116	70	306	85	4.0	2.6
80	88.9 x 3.2	25	850	150	—	450	350	80	580	205	—	116	80	330	70	4.4	2.6
100	114.3 x 3.6	32	850	150	—	450	400	80	630	237	—	120	100	394	40	4.7	3.0
125	139.7 x 4.0	32	950	170	—	600	500	120	790	252	—	120	100	422	100	5.4	3.0
150	168.3 x 4.5	40	950	170	—	600	500	120	790	266	—	133	100	450	85	6.1	3.4
200	219.1 x 5.9	50	1300	200	80	800	700	120	1020	292	372	139	120	602	80	7.7	4.0
250	273 x 6.3	65	1300	200	80	800	700	120	1020	329	409	198	130	676	50	8.5	5.0
300	323.9 x 7.1	80	1300	200	80	800	760	120	1080	354	434	165	140	736	40	9.4	5.3
350	368 x 8.0	2 x 80	1600	220	115	1100	900	120	1240	376	491	205	160	835	—	10.3	5.3
400	419 x 10	2 x 80	1600	220	80	1100	900	120	1240	402	482	205	160	852	—	11.3	5.3
450	457.2 x 10	2 x 80	1600	220	65	1100	900	120	1240	421	486	205	160	875	—	12.3	5.3

*External diameter x wall thickness

Source: Energie-Versorgung Schwaben AG, Kraftwerk Ulm, Einsteinstraße 20

Figure 13 (p 30) shows the steam network divided into two pressure levels. Two high pressure pipes in the north and the south transport the 15 atm steam from the HKW Magirusstrasse up to the take-off stations, where the pressure is reduced and fed with 3 atm into the steam distributed network.

Customer Installations

Customers were first connected to the district steam network in Ulm just after the pipe's installation in 1950. Each year after 1950, new customers were steadily added with a connected load of 12.15 MW (approximately 2,400 MWh per annum of supplied steam), until the customer base reached 836 at the end of the fiscal year 2003/04, with a current total connected load of approximately 200 MW. The heat distribution was increased in this period to over 300,000 MWh per annum. Figure 17(a) shows the development of the entire customer base; Figure 17(b) shows the annual customer increases.

A review of the customer connections corresponds well with the individual development phases previously described: the initial phase from 1950 until 1954; substantial development between 1955 and 1964; consolidation of development until 1974; the renewed development thrust between 1980 and 1984 and after 2000. These specific conditions in Ulm relate to the fact that the development of the district steam supply only began in 1950, and to the second oil price shock at the beginning of 1980.

Figure 18(a) shows the annual heat work since 1950;* Figure 18(b) shows that the heat distribution since 1978 has almost continuously decreased. These illustrations clarify that, despite increases in the number of customers, the heat distribution has almost continuously decreased since 1978. This can be explained as a long-term consequence of the oil price increases and a strengthened public environmental consciousness.

Since the late 1950 the medium connected load dropped from 0.43 MW/Customer to 0.23 MW/Customer. This suggests that the network serves neither a special network with residential buildings nor a special industrial network, although a decrease in median customer load suggests a tendency to fewer industrial customers with process steam requirement.

* Note that, in Figure 19, the annual sum of heat in 2002 is only listed until September: In September 2002 the FUG switch from calendar year to fiscal years, which starts with the 1st of October and ends with the 30th of September of the next year.

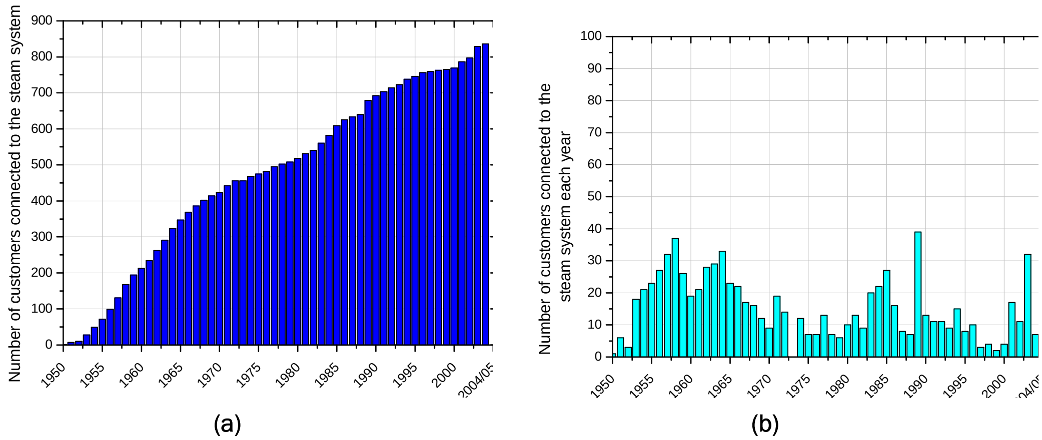


Figure 17. Development of (a) the number of customers and (b) the customer accession in the steam system between 1950 and the end of the fiscal year (FY) 2003/04.

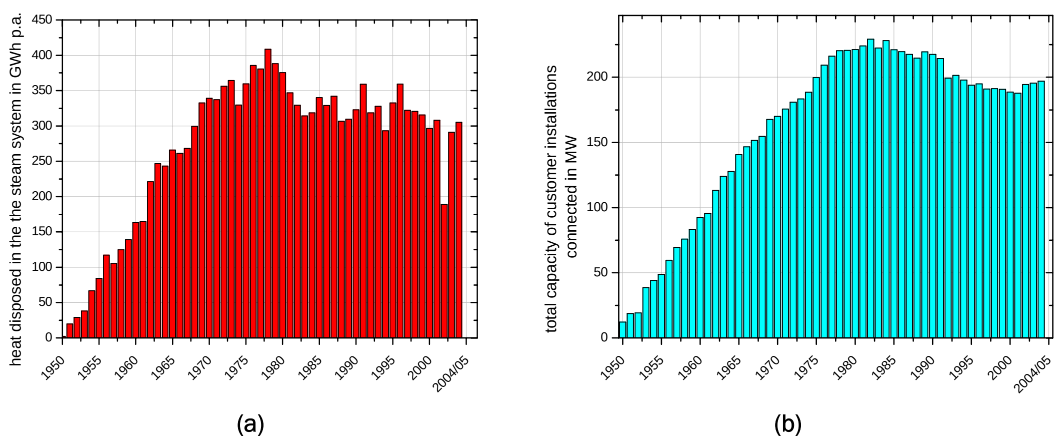


Figure 18. Development of (a) the steam distribution and (b) of the connected customer load between 1950 and the end of FY 2003/04.

Still, a small number of customers actually use steam in their processes: The city center has a few fashion boutiques or dry-cleaners, who would use steam for ironing or like operations. The Gold Ochsen Brewery, in the region of the Line North from HKW Magirusstraße to take-off station 3, uses a part of the process steam need from FUG-Steam network (Reserve Capacity: 8 t/h), as does the University Clinic (Reserve Capacity: 13.08 t/h).

4 Development and Evaluation of a Conversion Concept

The conversion of the steam network to the medium hot water systems is conceptually based on hydraulic computations. First, a hydraulic model of the steam network in Ulm was created using the hydraulic calculation program called *sisHYD* (Figure 19).

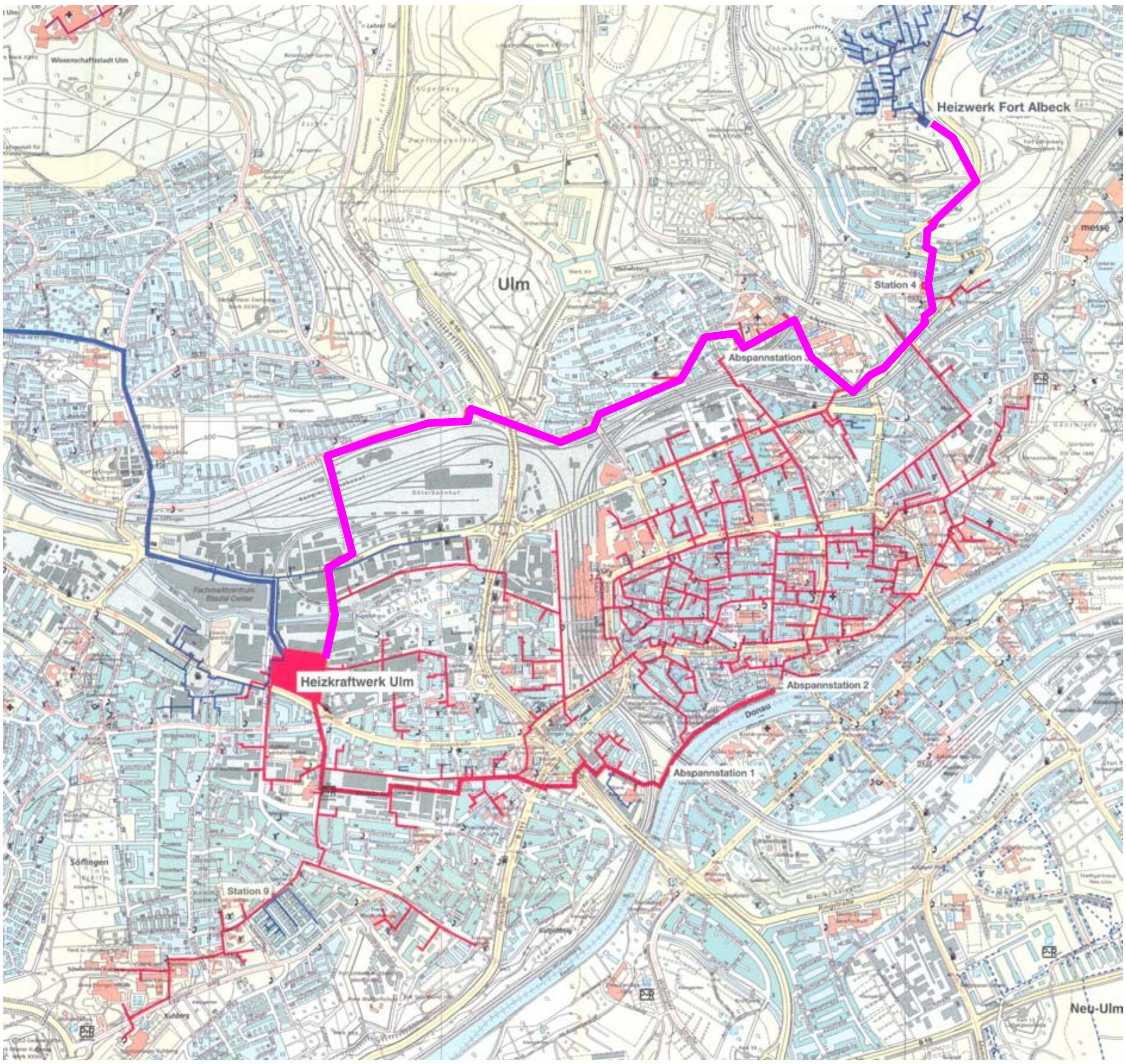


Figure 19. Cities Ulm and Neu emphasizing the steam DH system in Ulm including the highlighted Northern line.

After creating the model, the next step was to look for solutions that would give an idea to what extent it would be possible to convert the network of existing pipelines to hot water to meet the system's largest demand. The analysis considered special conditions in Ulm, including its relatively small nominally sized condensate lines.

A further characteristic of the Ulm steam network is the downstream secondary network, which involves the Boefingen/Eichplatz network. While there is a coupling to the Uni-network from the common production in the HKW Magirusstrasse, there is also a direct coupling over the so-called *Northern Line* to the Boefigen/Eichplatz network. It is clear that the extension of the North Line between HKW Magirusstraße and Step-down Station 3 up to the Fort Albeck heat plant runs under the Northern Line. Figure 19 shows a section of the steam network (from Figure 12) in large scale. The approximately 7.5 km Northern line is indicated in Magenta.

Figure 20 shows an area section along the Northern line, in which the difference in height of over 70m (not clearly seen in Figure 19) is evident. This difference in height is very important since the Böfingen/Eichplatz heating water system is essentially supplied by the HKW Magrisusstrasse via the Northern line. A heating water system would have to overcome a geodetic height of 70 m in on the last kilometers of the stretch.

The difference in height (a 15 atm and 3 atm operation modes, respectively, in winter and in summer) and the fact that the most important steam consumers (the *Gold Ochsen* Brewery and Uni-Clinic) are on this route, suggest that the conversion should begin by converting the steam network in the city center while maintaining the Northern line as a steam transportation line. This way, the customers on the Northern line could remain steam customers.

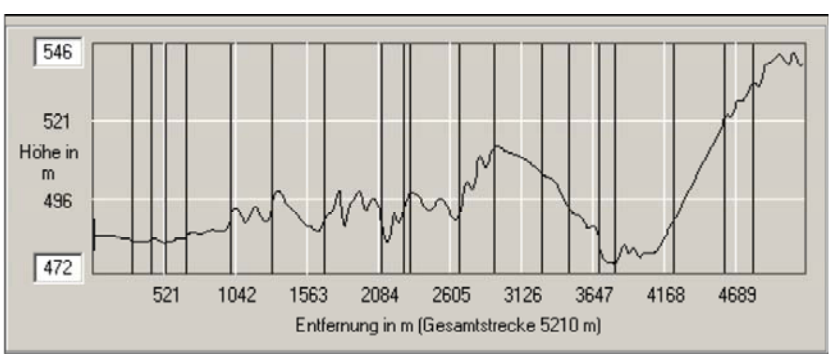


Figure 20. Cross section along the Northern line.

With this initial concept, it becomes possible to convert the existing system to a hot water system with the nominal pressure level PN16 and a maximum inlet temperature of 120 °C. This conversion concept integrates construction in the network with the generation plants.

4.1 Generation Plants

The fundamentals of the conversion concept have already been briefly addressed. Section 4.7, “Hydraulic Feasibility“ (p 44) further addresses the hydraulic aspects in detail. However, to maintain the production–network–customer order, “hydraulic feasibility” is considered first, following by system use, and then by the necessary investments in the generation park. To achieve the mentioned savings and additional necessary investments, this analysis assumes that the steam network (excluding the Northern line) will be converted to a hot water system with a maximum supply temperature of 120 °C and a maximum return temperature of 60 °C.

4.2 Savings Potential Generation

Similar to the initial situation in Munich, FUG proposed a plan to build a new generation plant in Ulm. Since this plant is still in the early planning stages, it has not yet been determined whether the plant will use steam or heating water extraction. Using hot water extraction will increase the current KWK plant’s capabilities and improve its economy, and will also yield potential savings for the existing generation plants, as shown by the following calculations for the existing biomass HKW (cf. Table 4, boiler 7 and turbine 7; Table 8).

Operation *without* extraction yields:

$$\Delta P_{\text{el}} = \frac{64\,\text{kg}}{3.6\,\text{s}} \cdot (2{,}758 - 2{,}692)\frac{\text{kJ}}{\text{kg}} \cdot 0.95 = 1{,}115\ \text{kW}$$

Operation *with* extraction yields:

$$\left.\begin{aligned} \Delta P_{\text{el,E}} &= \frac{25.6\,\text{kg}}{3.6\,\text{s}} \cdot (2{,}935 - 2{,}655)\frac{\text{kJ}}{\text{kg}} \cdot 0.95 = 1{,}892\ \text{kW} \\ \Delta P_{\text{el},GD} &= \frac{(64 - 25.6)\,\text{kg}}{3.6\,\text{s}} \cdot (2{,}758 - 2{,}692)\frac{\text{kJ}}{\text{kg}} \cdot 0.95 = 669\ \text{kW} \end{aligned}\right\} \Sigma_{\text{E, GD}} = 2.61\ \text{kW}$$

The average value on *both* modes of operation is:

$$\langle \Delta P_{\text{el}} \rangle = ½ \cdot (1{,}115 + 2{,}561)\ \text{kW} = 1{,}838\ \text{kW}$$

Therefore, a full load hour of 3,000 h per annum will result in (4) an additional generation of power of 5,514 MWh_{el} per annum in the existing Biomass-HKW.

Table 8. Calculation for the existing biomass HKW.

Extraction		Backpressure	
Present	As Per Conversion	Present	As Per Conversion
15 atm 240 °C max. 25.6 t/h	3 atm 150 °C max. 25.6 t/h	3 atm 150 °C	1.2 atm 120 °C

4.3 Condensate Losses

Compared to a steam network, a hot water system noticeably reduces both condensate and return losses. In 2003, the FUG steam network measured a condensate loss of 72,033 t; and in 2004, a loss of 66,427 t. This analysis calculated the avoidable condensate losses as the average of these two values, or 69,230 t per annum.

Based on experience, it is estimated that a steam network would lose about 60 percent condensation (or 41,500 t per annum). As stated before, the Northern line will retain its steam pipe. Still, the 41,500 t per annum along 7.5 km of the Northern line was reduced, so that only 47.4 km of steam pipe must be converted—resulting in an avoidable condensate loss of 35,800 t per annum The monetary advantage in reducing the length of condensate line is in avoided water purification costs.

4.4 Flue Gas Use

The relatively high moisture content of fuel wood gives the flue gas a high moisture content. Since converting the steam network to hot water reduces the temperature in the network, the energy contained in the flue gas can be at least partly used to preheat the return water of the DH system. Figure 21 schematically shows the relevant parameters in Ulm.

The idea is to use the high temperature flue gas (155 °C) and high humidity content to raise parts of the district heating return from approximately 55 to 60 °C to 80 °C through a heat exchanger. A flue gas stream with 164,000 Nm^3/h, corresponds to an output of 3.7 MW. By setting the parameters to 7,000 h per annum, the cogenerated heat was shown to save 26,000 MWh_{th} per annum

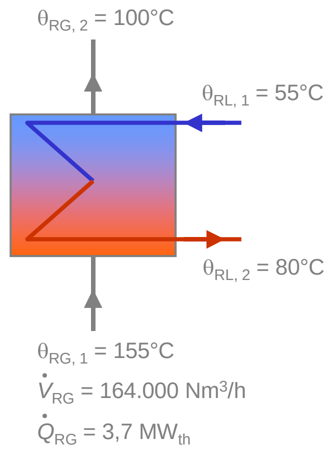


Figure 21. Schematic representation of a heat exchanger in the flue gas for the preliminary heating of district heating – runback in the hot water system.

4.5 Transformer Stations

New steam/hot water transformer stations must be installed to provide sufficient hot water capacity to meet customer load requirements. In the current steam network, the hot water maximum load is set to 100 MW (excluding the Northern line).

A transformer station was planned at the location of the Step-Down Substation 3 to provide a hot water feed from northern direction (from the Northern line) into the city network. According to FUG, it is possible to establish a transformer station there with the intended output of 15 MW.

Earlier it was mentioned that a new compressor plant with a district heating capacity of approximately 40 MW would be built at the HKW Magirusstrasse location. This plant can be designed using the current plan phase for hot water extraction.

This will provide a 55 MW heating water capacity. At least another 45 MW is of generating capacity will be needed to cover the maximum load of 100 MW in the future hot water system. In coordination with FUG, HKW Magirusstraße will add an additional 75 MW of capacity to transform the steam produced in the existing production plants to hot water.

4.6 Network

The following sections will discuss and quantify the costs and positive effects on the network resulting from a steam network conversion.

4.7 Hydraulic Feasibility

The conversion concept was shown to be hydraulically feasible based on:

- use of existing steam and condensate lines
- integration of the downstream hot water system (as in Weststadt)
- adherence to the nominal pressure level PN16, to avoid extensive exchange from nets.

The use of the existing network is required because the condensate line is of a small nominal size, which limits the amount of water it can accommodate, although it can tolerate a very high inlet temperature. The use of the more economical pre-insulated bound pipe system (plastic jacket pipe systems) will limit the maximum inlet temperature to 130 °C.

The combination of the steam network that has been changed over to hot water system with the existing Weststadt heating water system requires the standardization of operating and design parameters. For example, the customer stations in the Weststadt network, which are designed for a maximum of only 120 °C, must be safely adapted to accommodate a higher inlet temperature.

For this reason, the conversion was designed for a maximum supply temperature of 120 °C. However, in the future, the inlet temperature may be allowed to rise. Therefore, new components should be designed for a maximum temperature of 130 °C. Since the return temperature in the Ulm network is expected to be approximately 60 °C, the temperature differences for the network calculations were set at 120/60 °C.

The basic problem underlying the hydraulic feasibility of a steam network conversion using the existing network is small size of the condensate lines, which cannot be used to transport hot water. Nevertheless, an efficient new hot water transport system will be needed to use most of the steam/condensate network in the new hot water system. The existing network must be configured to allow subdivisions of the planned hot water system.

With a minimum differential pressure of 1 atm at the Netzschlechtpunkt, a maximum 12 atm was reached at the feeder in the HKW Magirusstrasse. Figure 22 shows a plot result of the network computation with colored graded results of the hydraulically critical return. Figure 23 shows a pressure diagram for this computation, showing the large difference in the hydraulic load between supply and return.

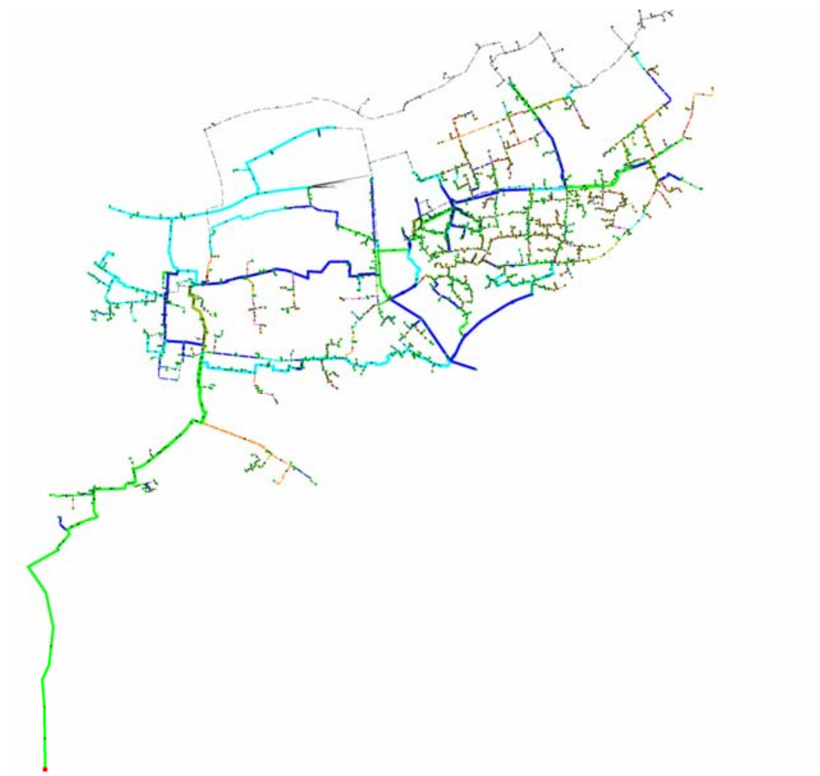


Figure 22. Result of a hydraulic calculation in case of 156 MW total load at minimum pressure of 1 atm; colors indicate pressure loss in the return pipes, from small losses (< 10 Pa/m) in cyan to high losses (> 1 kPa/m) in magenta.

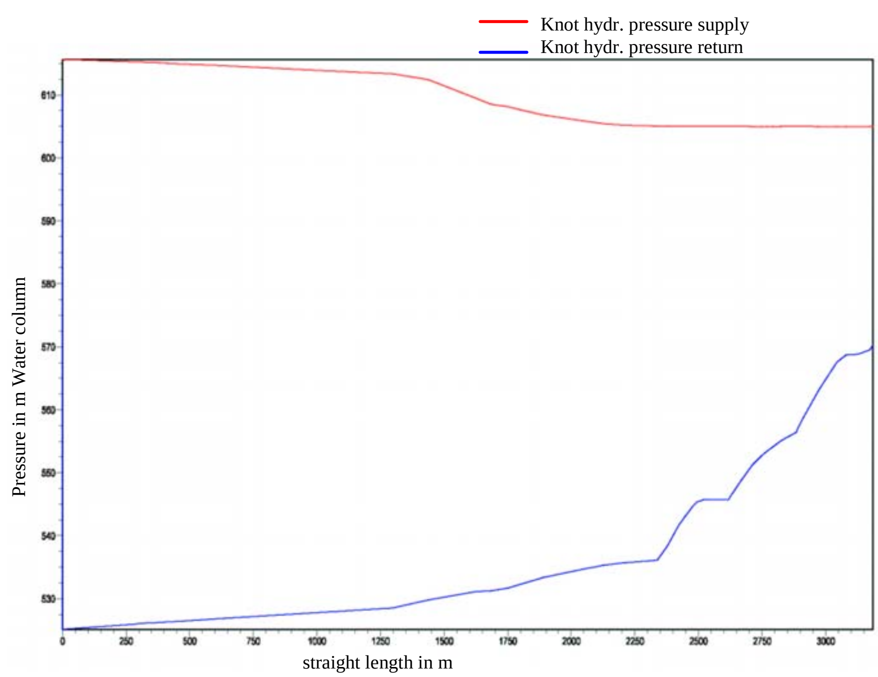


Figure 23. Pressure diagram in supply and return pipes along the way from von HKW Magirusstraße into the northern city (Wilhelmstrasse).

Where possible, parallel steam pipes will be used as supply and return pipe. This is possible in the area between HKW Magirusstrasse and step-down substation 1. Despite these measures, very small condensate lines must be replaced where the flow rates exceed 2.5 to 3 m/s. With these changes, a hydraulic network can be configured for the required maximum heat load (supply temperature) of 120/60 °C, which will:

- include the existing steam network (but exclude the Northern line and Bofingen/Eichplatz)
- include Weststadt
- include Donautal/Wiblingen
- include Neu-Ulm
- exclude Uni-Leitung.

Assuming that a maximum load of 40 MW must be transferred to Donautal/Wiblingen, the resulting calculated total maximum load is 156 MW.

4.8 Static Mechanical Feasibility

Table 7 lists the spans for steam and condensate lines that (depending on their nominal size) can be kept. Standard interpretations calculate the spans using a maximum water level of one third the total capacity.

However, to use the existing lines as heating water lines to the end of their technical lifetime, the maximum spans were calculated assuming that the pipes were completely filled. Table 9 list the results for the individual nominal sizes and for the associated spans according to FUG worksheet.

Even in the most unfavorable case, a steam pipe DN450, the 17.29 m values falls within 29 percent of the given span of 12.30 m. Moreover, the pipes laid in Ulm have a suitable wall thickness for use with the nominal pressure level PN16. Thus it can be assumed that the existing pipes are fundamental suitable for use as hot water lines. Note that this observation does not include very old (some up to 55 years old), or damaged piping.

Table 9. Existing width between two supports in steam and condensate pipes in Ulm as given in the standard working sheet and acceptable width between two supports in case of filling the pipes with water for different nominal diameters.

DN	Width Between Supports in Worksheet of FUG (m)		Acceptable Width Between Supports in Case of Water Infill (m)	Additional Safety In Steam Pipes (%)
	Steam Pipe	Condensate Pipe		
25	1.8	2.6	4.71	62
32	2.1	3.0	5.45	61
40	2.5	3.4	5.59	55
50	3.2	4.0	6.29	49
65	4.0	5.0	6.84	42
80	4.4	5.3	7.41	41
100	4.7		8.24	43
125	5.4		9.29	42
150	6.1		10.35	41
200	7.7		12.13	37
250	8.5		13.09	35
300	9.4		14.18	34
350	10.3		15.11	32
400	11.3		16.98	33
450	12.3		17.29	29

Investments for Replacement

The conversion of steam to hot water with the accompanying temperature reduction makes it possible to use more economical plastic jacketed pipe systems (pre-insulated bounded pipe) to replace the canal structure. This will reduce the cost to replace damaged pipe and pipe that has already past its normal service life.

It is assumed that the average technical life span of a steam pipe is 60 years and that many evenly distributed pipelines must be replaced at an earlier or later time. To simplify design fundamentals, this analysis used an average technical life span of 60 years (Figure 24).

Note: Pulling the normal distribution together leads to a rise of the replacement probability after 60 years, so that the probability for the replacement of a steam pipe in the case of the black distribution equals 100 percent. The representation of the three distributions (green, red and black) clearly shows that the green and red distributions are strongly elevated. Mathematically, they represent the integral during the entire period, for all distribution beginning with zero and continuing from 1 and 100 percent (i.e., the normal distribution).

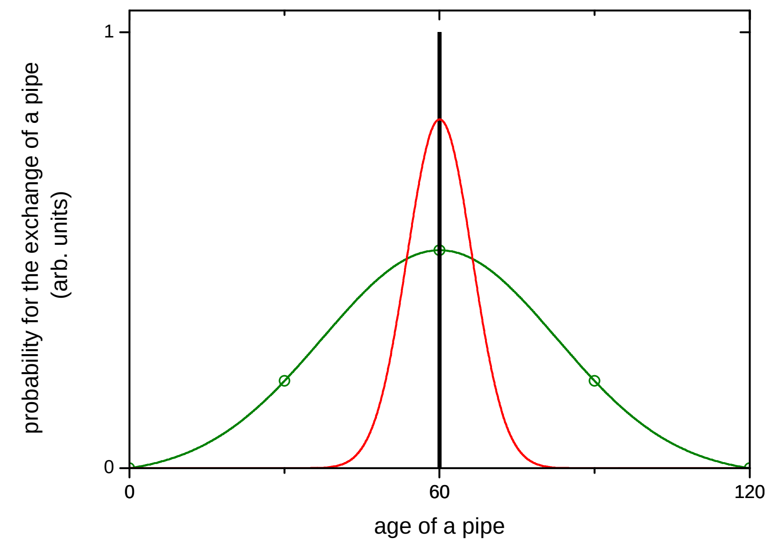


Figure 24. Diagram of a normal distributed aging and replacement probability of steam pipes.

At the maximum technical life span of 120 years, a steam pipe is exchanged within the period, where the Gauss Normal Distribution is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2 \right],$$

Integration during the entire period starting from the year of the laying results in:

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^\infty \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2 \right] \mathrm{d}x \equiv 1.$$

Here the expectation μ is set to 60 years. The parameter σ is the standard deviation, which decreases by one ($\sigma \to 1$) over the red to black; i.e., the dispersion of the distribution goes against zero.

Figure 24 shows that the probability for piping replacement follows a normal distribution and that the greatest probability occurs after 60 years. The green curve of normal distribution represents the highest peak. To simplify the computation, this Gauss distribution can interpreted to mean that the probability of replacement after 60 years is 100 percent even though in the mathematical model, the integral is only equal to 100 percent across the entire distribution (see notes to Figure 24). Figure 24

shows the age distribution of the piping in the steam network without the Northern line.

An evaluation of the advantages of pipeline replacement using pre-insulated bounded pipe technology instead of canal structures must include the specific construction costs and the reduced distribution of aging pipe in the Northern line (Figure 24). Specific construction costs for a pre-insulated bounded pipe-system and a canal structure must include the dismantling of existing, defective lines. Table 10 lists the construction costs. Note that the change to hot water in pre-insulated bounded pipes will require piping of a larger nominal size than for a comparable steam system.

Savings calculations used the specific construction costs of building hot water lines with pre-insulated bounded pipe of small nominal size (Figure 24) in accordance with Figure 23. Figure 25 shows the length distribution of the steam pipes against nominal size and year, and Figure 26 shows the result for the five-classes in Figure 25. The first chart plots the construction costs for the canal and pre-insulated bounded pipe-systems next to each other. Figure 26 shows the savings (differences between the two options on the same ordinate scale) associated with pre-insulated bounded pipe.

Table 10. Comparison of the specific construction costs for replacing an existing steam pipe by canal structure and pre-insulated bounded pipe system.

DN-class	∅ DN Trench	Costs Trench [EUR/M]	∅ DN Pre-Insulated Bounded Pipe	Costs Pre-Insulated Bounded Pipe [EUR/M]
15-40	32	650	25	550
50-80	65	880	50	740
100-125	100/125	1.300	80	950
150-200	150/200	1.900	100	1.100
250-300	250/300	2.500	200	1.600
>= 350	400	3.300	300	2.300
Miscellaneous	Average	1.755	Average	1.207

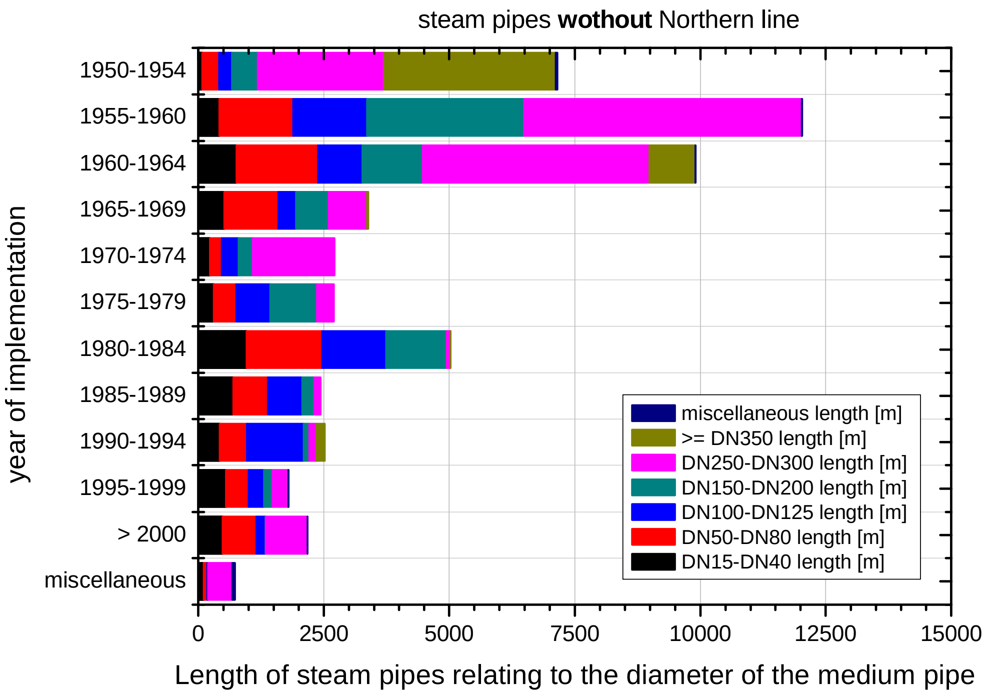


Figure 25. Length distribution of the steam pipes against nominal size and year of implementation without Northern line.

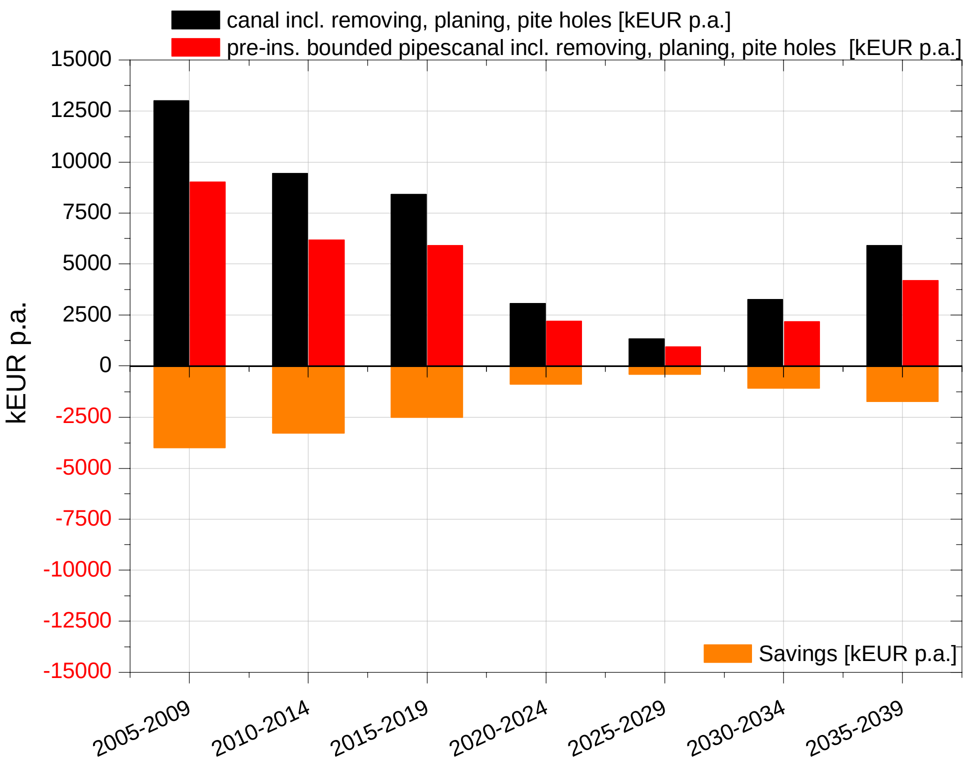


Figure 26. Savings with the anyway replacement investments by the employment of pre-insulated bounded pipe-systems in place of the canal structures in steam nets.

4.9 Future Pre-Insulated Bounded Pipe

The use of pre-insulated bounded pipe-systems has clear advantages over the canal structure. This was reinforced by a review of nominal sizes of pipe installed during the development of the steam network over the past 25 years, excluding the Northern line (Figure 27).

Table 11 lists the medium Pipeline add-in since 1980 by nominal size. This conservative projection assumes a reduction in future construction, although conversion to the steam network will increase future construction requirements.

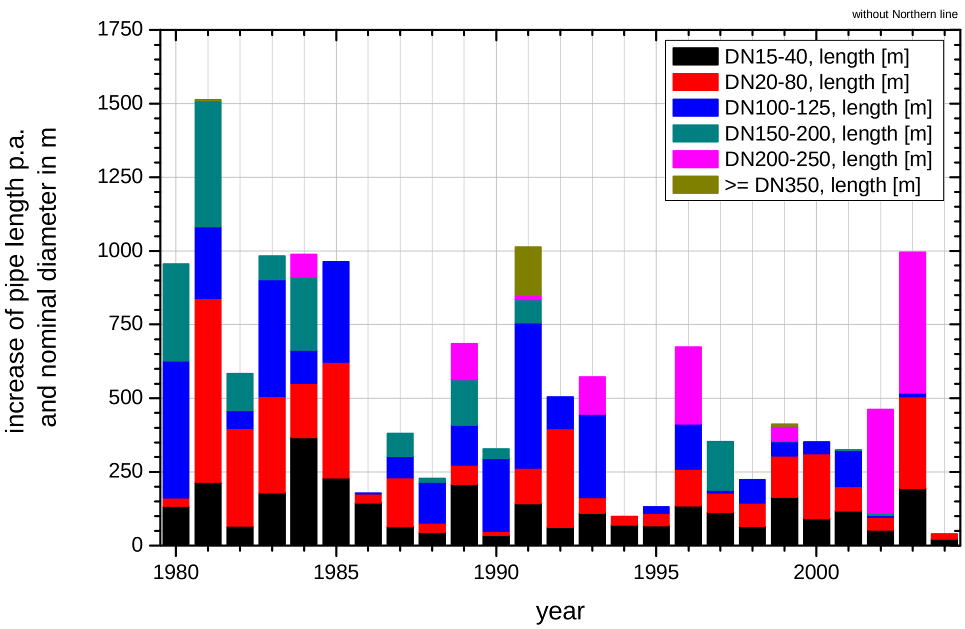


Figure 27. Yearly pipeline add-in in steam network against diameter without Northern line.

Table 11. Average pipelines built since 1980 and the projection used.

N-Class	Average New Built (m)	
	Since 1980	Future
DN15 ... 40	129	89
DN50...80	161	112
DN100...125	144	100
DN150...200	70	49
DN250...300	62	43
≥ DN 350	10	7
Account	1	1
Total	577	400

Table 12. Annual savings through the future network development with pre-insulated bounded pipe-systems.

DN Class	Cost Canal	Cost Pre-insulated Bounded Pipe	Annual Savings
	[EUR/m]		[kEUR per annum]
DN15...40	500	350	13.35
DN50...80	620	420	22.40
DN100...125	970	520	45.00
DN150...200	1,100	600	24.50
DN250...300	1,450	1,000	19.35
≥ DN 350	1,850	1,440	2.87
miscellaneous	1,082	722	0.36

The cost reduction listed in Table 12 is based on data in Figure 26 and Table 11, and results from the use of pre-insulated bounded pipe-systems in the future network construction.

4.10 Reduction of Operating Costs

Apart from the construction costs, operating and maintenance costs of the hot water system are less than those of the steam network. The hot water system's simpler system structure is less costly to maintain because it involves no complex condensate return.

This hot water DH system advantage is almost exclusively monetary, and should considered with other non-monetary advantages. Operating expenditures of the existing hot water systems in Ulm were compared with the operating expenditures of the steam network. The operating expenditures for the hot water systems Weststadt, Wiblingen, and Donautal are, on average, about 75 percent less than the operating expenditures of the steam network. Based on this empirical experience, the conversion of steam network can also be expected to yield a saving potential of about 75 percent relative to current operating costs.

4.11 Decrease of Heat Losses

An inherent advantage of converting the steam network to hot water is the decrease in heat losses. Evaluating this factor requires three steps:

1. Lower the annual average temperature
2. Decrease heat losses by constructing a modern pre-insulated bounded pipe-system
3. Optimize the new system by balancing the parameters described in section 4.7.

4.11.1 Lower the Annual Average Temperature:

In the year 2002, heat losses in the steam network (not considering the Northern line) amounted to approximately 49,000 MWh per annum. To ascertain the saving potential, it was assumed that about 40 percent, or 19,600 MWh per annum, was being lost through the uninsulated return lines, and about 60 percent, or 29,400 MWh per annum, to the supply lines in the steam network.

No reduction is possible in the return lines by converting to hot water since the future return temperature will correspond for to the current condensate temperature. Therefore, in this case:

$$Q_{\text{lost, RL, Dampf}} = Q_{\text{lost, RL, Heizwasser}} = 19.600 \text{ MWh per annum}$$

However, savings can be obtained in the supply by reducing the annual average temperature from current 160 °C in steam to 95 °C in the future hot water system. Simply put, the linear relationship between heat loss Q_{lost} and lowered temperature, for the difference ΔT between the mid year inlet temperature T_{VL} and the ambient temperature T_{Umgebung} is:

$$Q_{\text{lost, VL}} \propto \Delta T$$

Thus future heat losses can be calculated as:

$$\Delta T_{\text{Dampf}} = T_{\text{VL}} - T_{\text{Umgebung}} = (160 - 20)\,°\text{C} = 140\,\text{K}$$
$$\Delta T_{\text{Heizwasser}} = T_{\text{VL}} - T_{\text{Umgebung}} = (95 - 20)\,°\text{C} = 75\,\text{K}$$

Therefore, in a future hot water system, the expected heat loss due to the temperature reduction is:

$$Q_{\text{lost, supply, hot water}} = Q_{\text{lost, supply, steam}} \cdot \left(\frac{\Delta T_{\text{hotwater}}}{\Delta T_{\text{steam}}} \right) = 29{,}4000 \,\text{MWh p.a.} \cdot \left(\frac{75}{140} \right) = 15{,}800 \,\text{MWh p.a.}$$

The sum $Q_{\text{lost, hot water}}$ from the expected heat loss in future in return $Q_{\text{lost, return, hot water}}$ and in supply $Q_{\text{lost, supply, hot water}}$ is calculated as:

$$Q_{\text{lost, Heizwasser}} = 35{,}400 \text{ MWh per annum}$$

Therefore, the savings potential for this step is:

$Q_{lost, steam} - Q_{lost, hot water}$ = (29,400 – 15,800) MWh per annum = 13,600 MWh per annum

4.11.2 Construct a Modern Pre-Insulated Bounded Pipe-System

If it is assumed that the specific heat losses per unit length of the piping can be reduced from 115 W/(m·a) in a current canal structure with steel lines to 50 W/(m·a) in a future pre-insulated bounded pipe-system, the savings potential for the Ulm steam network (excluding the Northern line) is:

$Q_{lost, PRE-INSULATED BOUND PIPE, hot water}$ = 47,400 m · 50 W/(m·a) · 8,760 h
= 20,800 MWh per annum

In relation to the heat losses computed in step 4.11.1 $Q_{lost, hot water}$ in a hot water system, which uses completely the existing lines, yields savings of:

$Q_{lost, total, hot water}$ = $Q_{lost, hot water} - Q_{lost, PRE-INSULATED BOUND PIPE, hot water}$
= (35,400 – 20,800) MWh per annum
= 14,600 MWh per annum

This heat loss saving can be obtained after a temperature reduction and a change of the entire network to a pre-insulated bounded pipe-network. Since the system conversion will not take place instantaneously, this reduction potential can reduced by half. Therefore the savings potential for this step is:

0.5 · $Q_{lost, total, hot water}$ = 0.5 · 14-600 MWh per annum = <u>7-300 MWh per annum</u>

4.11.3 Balance the Parameters in Steps (1) and (2)

Balancing the parameters described in steps (1) and (2) above yields the true savings potential on heat losses due to the conversion of steam network:

(1)	Reduction of the mid-year inlet temp.:	13,600MWh per annum
(2)	Reduced losses in the pre-insulated bounded pipe-network:	7,300 MWh per annum
(3)	Balance of step (1) and (2):	20,900 MWh per annum

4.12 Increased Need of Pumping Electricity

Beyond energetic (heat loss) and financial savings involved in operating a hot water system compared with a steam network, the additional neces-

sary expenditures include the need for pumping and its associated electrical demand.

In the described conversion concept, another feeding point is designed in the hot water system where Stepdown Station 3 is to be built through the transformer station Nord. (This is separate from the central production plant HKW Magirusstraße.) Therefore additional supply pumping capacity is necessary at this two locations.

At HKW Magirusstraße, a mass flow $\dot{m}$ = 330 kg/s, pressure p = 7 atm, and a pump capacity of 340 kW is necessary, corresponding to a pump motor capacity of about 380 kW.

The transformer station Nord requires a mass flow $\dot{m}$ = 60 kg/s, pressure p = 5.5 atm, and a pump capacity of 49 kW is necessary, corresponding to a pump capacity of approximately 60 KW.

In total, pumps with a motor power of 420 kW must be in place to operate the hot water system. The additional expenditure can be expressed in the units of electrical work $A_{\text{Pump, el}}$ necessary for operating the pumps. At a full load hour of 7,000 h per annum, this electrical work is:

$A_{\text{Pump, el}}$ = 2,940 MWh per annum

4.13 Network Strengthening

The existing network is appropriate for the nominal pressure level PN16. Nevertheless, some measures must be taken to improve the efficiency of the existing pit installations and to reinforce certain fixed points to operate a hot water system.

First, existing drainage systems must be dismantled. Afterwards the exhausts and drains will be reassembled in the condensate system. A conservative estimate suggest that this will involve half of the pits in the conversion of steam network. Since the Northern line will remain a steam transportation line, the 100 pits on that line are not involved, leaving the remaining 525 pits to be improved for efficiency.

Second, fixed points must be reinforced. For reasons of symmetry, the larger forces applied to the system when it is being filled with water affect only a small number of fixed points (a maximum of 60 points). These 60 fixed points must be strengthened in the course of conversion.

Third, a pressure test must be done before the final set-up and operation of the tubing section changed over to hot water. Experience with the conversions done in Munich and Salzburg have shown that this measure can taken by operator's personnel. This required three workers from FUG for each conversion phase. Since a conversion step is limited to approximately 5 weeks, each step should require about 600 work-hours. FUG's expenditure for these pressure tests, for a maximum of six conversion steps totaled 3,600 work-hours.

4.14 Reinforcement Routes

The basic idea used in the Munich conversion was to largely use existing lines as hot water supply and return. In Munich, this could not be done without annexing some reinforcement routes. Hydraulic investigations have also shown that a similar annexing of reinforcement routes is inevitable in Ulm. Figure 28 shows the reinforcement lines resulting from hydraulics.

The number of 10-line sections to be built is the most cost-intensive measure required to strengthen the existing network, and to realize a medium change to hot water. A new hot water connection with line 1 is needed in the east part of the city center. Arriving at the station as the "Ostspange," this line divides itself into the line sections 2 and 3. Line 2 up to the Stepdown Substation 1 ensures a hot water supply from the south. Starting from the Stepdown Substation 1, a future Danube crossing is possible e.g., along a railway bridge, making a connection with the SWU-District heating network possible in New Ulm.

A new main supply of hot water will be developed using line 3 and the extension of lines 4 to 7 in the city center. This will use the Ulm 21 development project. This development project is closely connected with the modernization of the main station, and includes plans for a pedestrian bridge over the railway tracks. This pedestrian bridge can be used as the simplest way to make the mentioned connection over the track body. The city moat can also be used as part of the existing route.

Line 8 starting from the transformer station north (UFO Nord) represents the connection between the new hot water main line and the northern feeding point.

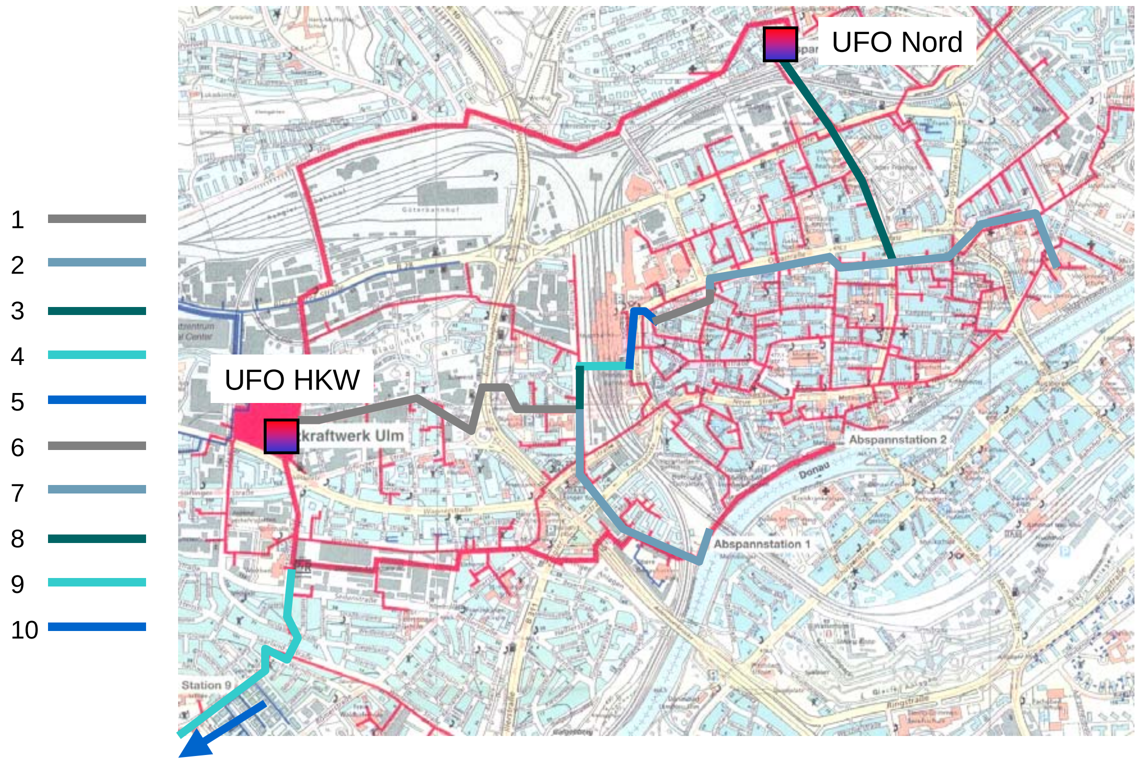


Figure 28. Required hot water pipe backbone (Note: UFO stands for transformer from steam to hot water).

Lines 9 and 10 are the connection to the Kuhberg supply area in the southwest of the HKW Magirusstrasse (line 9), and also the connection between the HKW Magirusstrasse and the heating station Daimlerstrasse (line 10). The extension of the connection starting from *Kuhberg* up to the heating station Daimlerstrasse is no longer necessary for the steam network conversion. However, the steam network conversion offers the possibility to specify a FUG utility system connection to the FUG individual *Donautal* and *Wiblingen* nets.

The effects of such a connection line are not independent from the steam network conversion, since in the course of the pipe installation at the steam network area, *Kuhberg* will be changed to hot water, in which case, a connection line may already be planned. In fact, *Kuhberg* is a special case since the surrounding town development areas (e.g., Kohlplatte, Lindenhöhe) offer a connection potential for a line-bound heat supply. Table 13 lists the necessary cross sections of a line, the approximate route lengths, and the necessary specific expenditures for the feeder line.

Some strengthening of house service connections will be necessary due in part to the very narrow condensate lines (not shown in Figure 26). Hy-

draulic calculations indicate that these house connections must be strengthened by installing reinforcement lines with a length of approximately 3,120 m in nominal sizes between DN40 and DN100. Table 13, line 11 lists the cost.

Table 13. Needed cross sections of pipe line, approximate route lengths as well as specific construction costs of the reinforcement lines.

Line	Nominal size (DN)	Length [m]	Specific Costs [EUR/m]
1	500	1,600	1,800
2	300	670	1,300
3	250	141	1,000
4	250	190	1,500
5	250	280	1,200
6	250	259	1,000
7	250 200	690 570	1,000 900
8	200	730	900
9	350	1,450	1,450
10	350	2,860	1,450
11	40 to 100	3,120	400 to 600
Total		*12,580*	

4.15 Customer Stations

Experience in Munich shows that two types of customers cases must be considered:

1. Customers who do not need steam for processes. This circumstance justifies a complete change of all customer stations with steam heat exchanger to hot water compact stations, a basic condition for a successful steam network conversion.
2. The customer who requires further steam for processes. This circumstance requires investigation of the nature of the steam demand, whether another heat/energy source (besides steam) may fill the customer's needs, or, where there is an absolute need for steam, whether it can be supplied locally.

4.15.1 Change of Customer Stations

As a rule, heat energy is transferred from the steam network via a heat exchanger, and is then used in a secondary, hydraulically separate circulation in the building. Typical uses are space heating and service water

warming. These cases require a change of the existing customer station to a district heating compact station independent of the age of the existing plant.

In Ulm, customer stations are normally the property of customers. In such cases, the customers would bear the full cost of the change. Since this would not be acceptable, particularly if the customer station had only been operated a few years, the district heating operator must appropriately invest in the change of customer stations. This is a charge must be calculated as part of the cost of steam network conversion.

To measure the extent of such compensation in advance would require knowing age distribution of the customer stations. However, the FUG data is limited to the information shown in Figures 17 (a) and (b) and 18 (b). The number of customers and the system performance by year is only known since 1950. Data on when customer stations were attached to the steam network or when they was replaced are not available. To compensate for this lack, a model approach was developed based of renovation cycles, which shows that a customer station is operated at least 30 years before it is changed. Furthermore at least 20 percent of all customer stations are changed after 40 years, 50 percent after 50 years, 80 percent after 60 years, and 99 percent after 80 years. This results in a renovation cycle in form of an exchange probability (Figure 29).

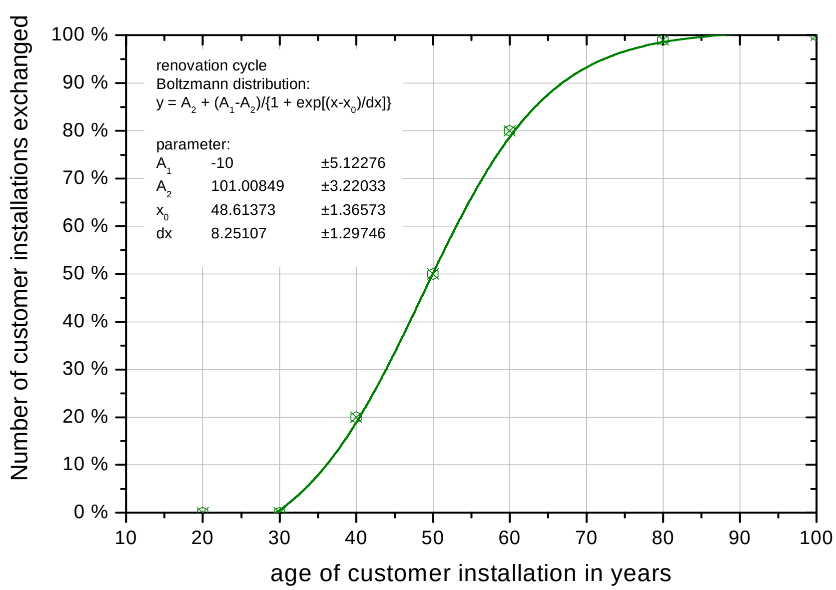


Figure 29. Renovation cycle of customer installations basing on a Boltzmann distribution.

The Boltzmann-Distribution can be expressed as:

$$f_{\text{Boltzmann}}(x) = A_2 + \frac{A_1 - A_2}{1 + \exp\left[\frac{x_1 - x_0}{\mathrm{d}x}\right]}$$

where:

$A_1 = -10$
$A_2 = 101.01$
$x_0 = 48.61$
$\mathrm{d}x = 8.25$

The Boltzmann-Distribution serves to determine the percentage of customer stations that has been changed each year. The age of customer installations from Figures 17 (b) and 18 (b) must be altered so that the changes arising in a year in which the customer stations were renewed as per Boltzmann are applied as the basis for the subsequent year's calculation (i.e., this is a dynamic computation). The goal of this method is it to include the possibility of repeated change of the house transfer station of the same customer. The result is an age distribution of the capacity of customer installations in the steam network (Figure 30), excluding Northern line customers.

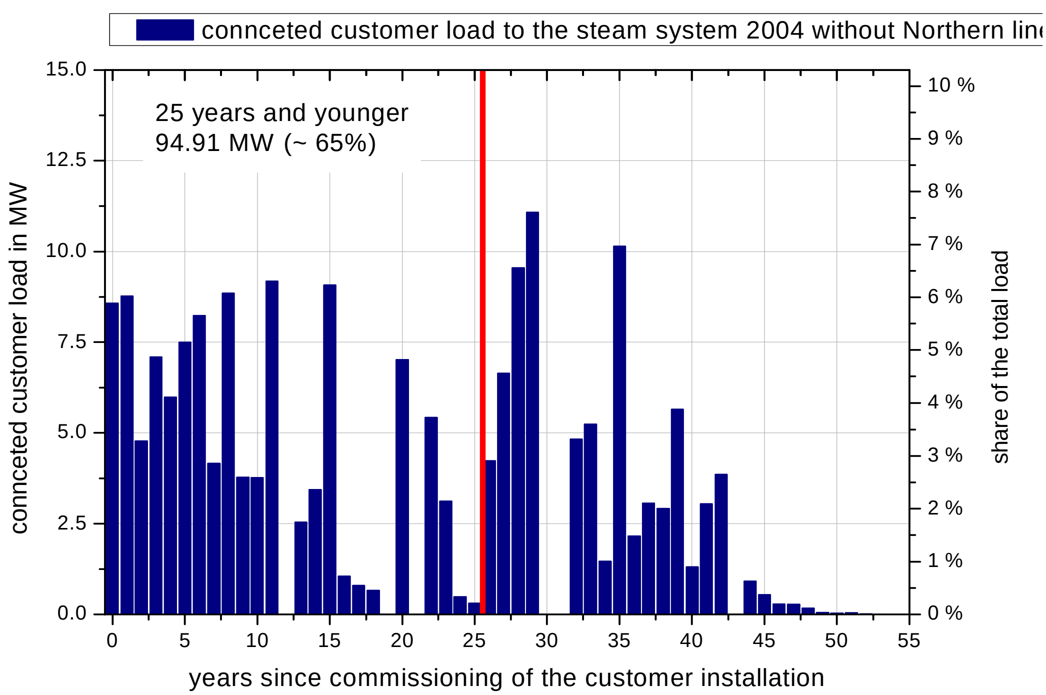


Figure 30. Re-calculated age of customer installations.

The red section ATM drawn in Figure 30 divides the customer stations into those that are no more than 25 years old (left of the section atm) and those 26+ years old (right of the section atm). The new calculation of the age structure shows that about 65 percent of all customer installations are less than 26 years old, nearly 95 MW. A subsidy must be applied to these 95 MW in the case of a steam network conversion.

4.15.2 Alternative Solutions for Customers with Existing Steam Requirements

Alternative solutions (or, at least, co-financing by FUG) must be developed for customers on the current steam network who still need steam. Since the conversion concept retains the Northern line as steam pipe, the largest steam users (the Gold Ochsen Brewery and the university clinic) require no specific action. These customers will also be supplied with steam after a medium change.

Alternative solutions for steam customers in the conversion area might be for them to supply their own steam generation, possibly using a system based on hot water supply. Another alternative may be to change the complete system. Such businesses as fashion boutiques and dry-cleaners, for example, could use electric steam irons. Steam kitchens, similarly, could use electric or gas stoves.

5 Economic Factors of the Conversion Concept

Previous chapters have discussed the technical and hydraulic feasibility of the concept of converting steam networks to hot water based on the Munich model and considering the specific circumstances in Ulm. The technical advantages of conversion from steam systems can be summarized as:

- Hot water systems are easier to control. Hot water temperature and flow can be adjusted. The fact that steam pressure determines its temperature makes it difficult to vary the pressure; flow is the only remaining way to change the rate of heating.
- Hot water systems require less maintenance.
- Hot water systems are safer.
- Hot water systems are less prone to leak.
- Hot water systems' distribution piping systems last longer.

Notwithstanding these advantages, several barriers to the application of CHP systems at Army installations do exist:

- The existing heating boilers do not produce the high pressure steam required for efficient generation of electricity.
- Absorption chillers would be needed to enhance the summertime thermal load so that year-round electrical generation would be attractive. Thermal storage systems may also be required.
- Current CHP personnel probably do not have the training to operate and maintain electrical generation equipment.
- Current fuels used on Army posts are typically natural gas and fuel oil. Coal may be the choice for the CHP plant requiring new and amended contracts to purchase the desired energy source, and environmental permitting changes.
- For some electrical contracts, several Army posts are grouped together for a utility wide rate schedule. A new rate schedule would be required with the addition of a CHP plant.

To justify a full conversion, a life-cycle analysis is needed that considers all changes and associated costs. However, the decision to convert a steam network to hot water cannot depend on technical and hydraulic feasibility alone; it must also have a sound economic basis. Consequently, FUG financed an economic analysis to include the boundary conditions specific to Ulm.

This chapter summarizes a general, fundamental economic analysis including enterprise-sensitive rates and remuneration. To compute the economic factors, an annuity of 10 percent was used to calculate necessary investments. Operating costs and savings were on a yearly basis.

The expected result after a complete conversion is a system with an increased economic value.

5.1 Production Plants

The description and evaluation of the conversion of production plants has shown cost saving in three of five points (Section 4.2, p 41):

- future avoidable condensate losses at a value of 35,800 t per annum (Section 4.3, p 42)
- electrical co-generation using existing biomass HKW at a value of 5,514 MWh_{el} per annum (Section 4.2, p 41)
- additional heat gain from flue gas at a value of 26,000 MWh_{th} per annum (Section 4.4, p 42).

Required investments for the heat exchanger in the flue gas stream and the for additional transformer stations:

- building 3.7 MW heat exchanger in the flue gas (annuity contribution) (Section 4.4, p 42)
- building two transformer stations (UFO center and UFO north) together with 90 MW_{th} (annuity contribution) (Section 4.5, p 43).

This yields total savings (for production plants) with a value of 995 kEUR per annum.

5.2 Network

The conversion will realize both costs and savings in network improvement measures and the network construction including the increased need for pumping electricity, savings in replacement investments, more favorable future network development, and reduced operating cost and heat losses. Network savings are:

- Over the next 35 years, reduced replacements investments (annuity contribution) (Section 0, p 47)
- In the future, a more economical construction of the network with pre-insulated bounded pipe-systems employing existing canal systems (400 m per annum) (Section 4.9, p 51)

- Lower operating and maintenance costs in a hot water system in comparison to the steam network (Section 4.10, p 52)
- Reduced heat losses by sinking the mid-year inlet temperature and future construction using pre-insulated bounded pipe-systems (at 20,900 MWh per annum) (Section 4.11, p 52).

Additional expenditures include:
- Additional requirements for electric current for pumps in the hot water system at a value of 2,940 MWh_{el} per annum (Section 4.12, p 54)
- Total expenditure for network strengthening measurements (adjustment of 525 shafts, reinforcement of 60 fixed points, and salary for three workers every 5 weeks for maximum of 6 changeover years) (annuity contribution) (Section 4.13, p on page 55).
- Investments to build strengthening routes, some lines of which may be consolidated with the FUG part of the steam network conversion (annuity contribution). The reason for only partly assigning the investments for strengthening lines was (as discussed in Section 4.13, p 55), for example, that the building of the connecting line from the Kuhberg to the Daimlerstrasse heating station is not necessary for the steam network conversion. However, it is best to take the additional capacities into account for a possible later connection, e.g., to new Ulm. The same applies to the pipeline sections 1 and 9 (Section 4.14, p 56).
- Additional annual expenditures were taken into consideration to account for unforeseeable technical uncertainties, spontaneous damage, and other complications.

Altogether, a conservative estimate of the network sector shows a saving potential of about 770 kEUR per annum.

5.3 Customer Stations

Customer stations can anticipate no reduction in operating costs or avoidance of investments through a steam network conversion. In fact, necessary expenditures to accomplish a medium change are:
- Subsidy by FUG to change all customer stations in the steam network. On the basis of computed age distribution (Section 4.15.1, p 58), newer customer stations are more strongly subsidized than older stations (Figure 31). This results in an annuity contribution (Section 4.15, p 58).
- Annual expenditure for interim and alternative solutions for customers who still require steam after the conversion (Section 4.15.2, p 61).
- Annual expenditure as security for unexpected expenditures within the scope of customer stations.

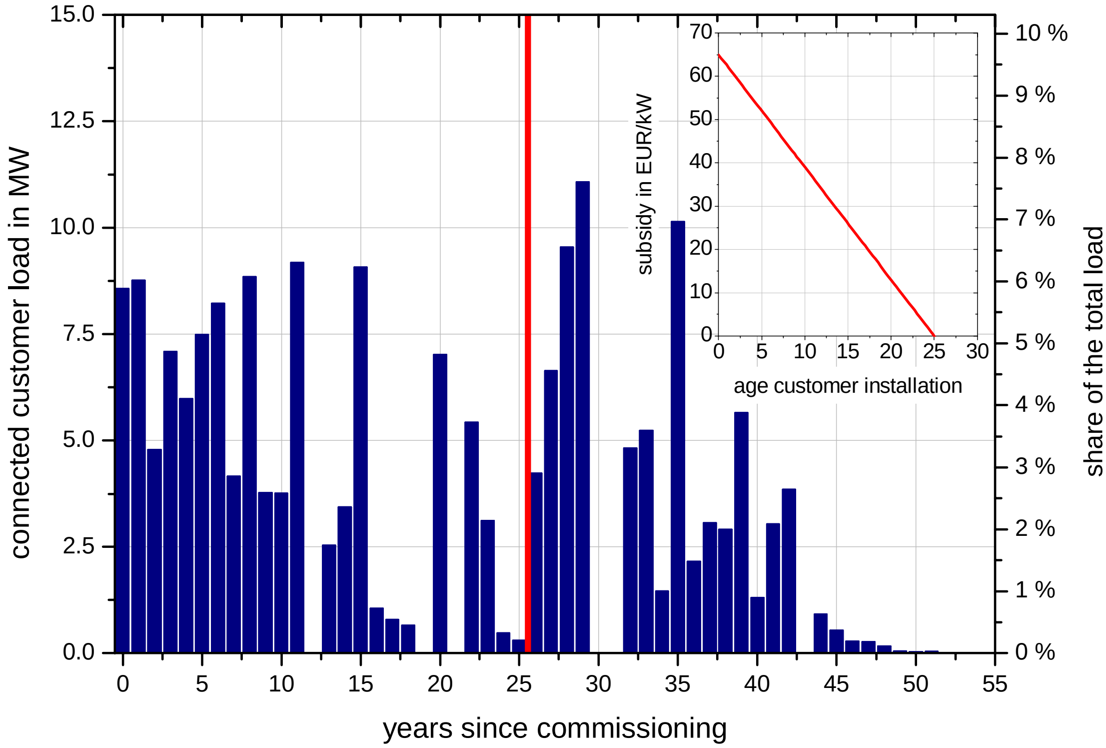


Figure 31. Linear depreciative subsidy model for changing the customer stations

Altogether auxiliary expenditures for customer stations sum about 590 kEUR per annum.

5.4 Total Evaluation

The total over the three ranges of production plants, nets, and customer stations, summed using static calculations of production costs, yield possible savings of 1,175 kEUR per annum.

These savings include numerous securities and conservative calculations of production costs. However, production costs were calculated based on static calculations; dynamic calculations, e.g., computations using the present value method or other similar methods were not possible in the context of this transferability study. The basis for such dynamic economic analyses (e.g., the spatial allocation of the yearly conversion step) was not available for this study.

5.5 Lessons Learned

The results of the steam to hot water conversion in Munich largely using existing nets and customer stations, may be applied to small steam networks such as the network in Ulm.

As in Munich, the steam network conversion in Ulm will require constructing additional lines to form a kind of "backbone" to the hot water supply. In Ulm, it is possible to economize by reusing the existing steam and condensate lines in a hot water system if, in the course of the conversion, house service lines are sufficiently extended in critical places. Note that, to ensure customer acceptance of the conversion, calculated costs must include subsidies to change the customer stations. Local conditions require a comprehensive restructuring of Ulm's antiquated steam nets into a modern heating water system, with the specified new building line and new compressor plants.

6 Operating and Ownership Considerations

6.1 System Expansion and Economic Considerations

6.1.1 Methods To Increase Distribution System Capacity for Newly Added Customers

In Europe, pre-insulated plastic jacket pipes are frequently used in district heat distribution systems. Depending on the static conditions of the distribution pipe (strain and expansion), it is generally possible to connect new pipes to pre-insulated pipes.

MVV Energie in Mannheim connects new customers to the network by a method called “spot boring,” which allows new customer connections without interruption of the supply to existing other customers — a big advantage of that method.

In Europe there are centralized DH systems up to several 1,000 MWth in operation. The system of MVV Energie AG has a capacity of 1,000 MW and supplies a population of ca. 200,000 people via roughly 10,000 individual heating transfer stations. The length of the system is roughly 500 km, and the DH network belongs to MVV Energie AG.

MVV Energie has an Energy Supply Concept to avoid competition within the service area. The idea is to not to “block” competition, but to optimize the resources to be able to offer to the clients the best price. This concept divides the Mannheim city area into priority zones for District Heating, Gas, and Power service areas. Table 14 lists the criteria for this concept.

Table 14. Criteria for MVV Energie energy supply concept.

	DH Priority Zone	Gas Priority Zone	Power Priority Zone*
Available energy	Power District heating	Power Gas	Power
Covers the following demands	Heating, lighting, power, cooking etc.	Heating, lighting, power, cooking etc.	Heating, lighting, power, cooking etc.
Heat density (indicative)	High, city center	medium	Low, buildings very far from a gas or DH grid

* MVV Energie offers a “night time” tariff for user of power heating accumulators, which is competitive to DH tariffs.

The concept is based on economic and environmental criteria and resulting calculations. The district heat is generated in a large CHP plant and the supplied heating water can be delivered for a competitive price. Customers are not obliged take the MVV Energie service; they are free to install individual small light oil boilers.

Based on this energy concept, the MVV Energie marketing department solicits potential customers for connection to the grid. When a potential customer applies for connection, the MVV Energie engineering department does a hydraulic check of available capacity at the requested service area. If the connection is feasible, the customer gets a contract and MVV Energie delivers a substation (for the required capacity) to the new customer, and then connects the new customer to the network. This mechanical works is finalized normally within 1 week. New customers are connected to the network by spot boring. For large connections to the main pipes (above DN 125), a provisional connection is installed. No interruption of supply to other customers occurs. Figure 32 outlines the process.

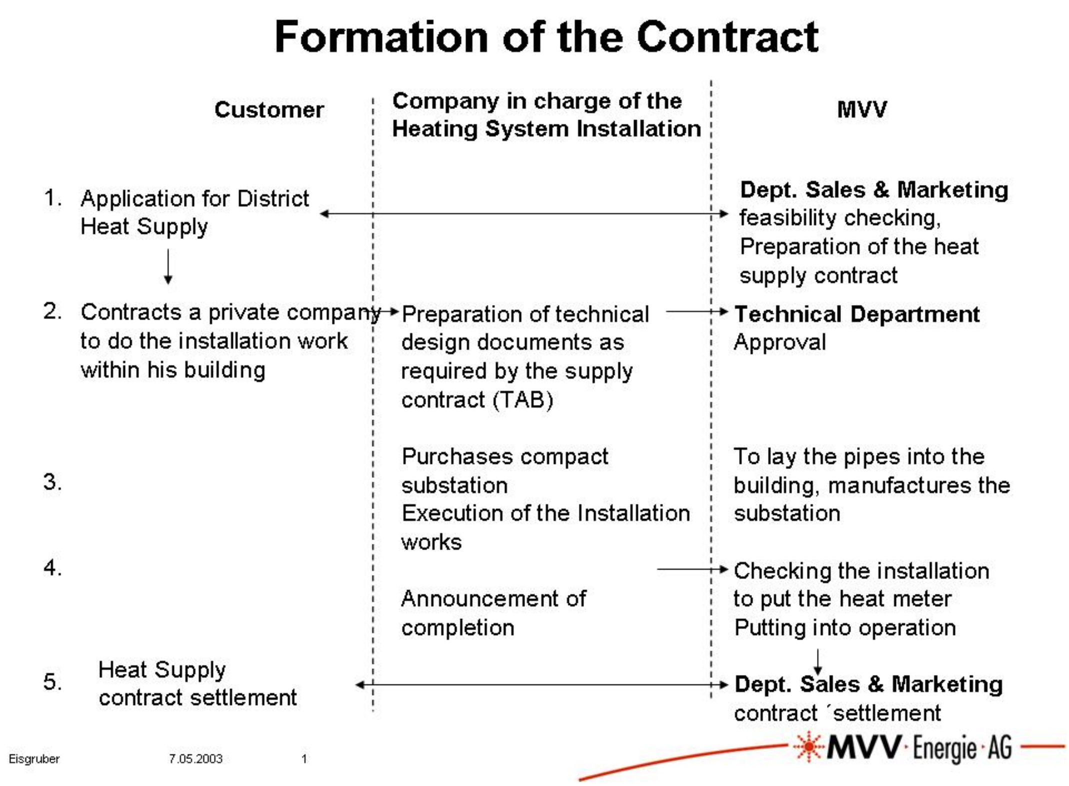


Figure 32. Process to establish a new customer contract.

Generally, methods to increase (hot water DH system) capacity are:

- *Decrease the return flow temperature much as possible*. This leads to a higher value of temperature difference and finally to a higher capacity of the DH network
- *Use control equipment (thermostatic valves, flow regulation, variable system regulation)*. This leads to a small coincidence factor (The required system capacity is significantly lower then the total sum of the capacity demands (loads) of all individual customers. (For example, the sum of capacity demand of MVV Energie's DH customers is roughly 2000 MW, the real peak load is 850 MW, and the coincidence factor is 850/2000 = 0.425.)
- *Apply energy saving projects at the end user side, such as thermo insulation of buildings, double glass windows*. These measures can achieve up to 50 percent reduction in demand. The German Government promotes such measures in private owned buildings with soft loans (e.g., via the "CO_2 reduction program of the German Government").

The entire process, from the end user, to distribution, to production facilities must be viewed holistically. From a technical and economical point of view, system optimization should start with energy saving measures at the end user side to avoid inadequate capacity in the production and distribution system. A good pricing system for district heating service should include fixed and variable components. The variable component should somewhat reflect long-term marginal supply costs. These should be taken as a basis for calculating economic feasibility of energy efficiency measures on the customer side.

6.1.2 Expected Life and Cost of Replacement of Major Components

Pre-insulated, plastic jacketed pipes are commonly used in district heat distribution systems in Europe, often together with maintenance-free fittings. Today ball valves are usually applied. These fittings are connected to the pipes without flanges; they are welded to the pipes. Therefore no sealing has to be changed at regular intervals. For smaller pipes, no fittings are installed for draining and exhausting the pipeline.

Pipe sections or fittings will only be replaced if there are leakages. This maintenance philosophy is as an "event-driven" strategy, in which it is very important to detect leakages in a very first state by applying leak detection methods at regular time intervals. Many of the pre-insulated pipes have an electrical leak detection system built into the insulation.

Table 15 lists estimated values for the specific installation costs of pre-insulated pipes, laid in settlement areas or areas with unfortified surface.

Table 16 lists the estimated values for specific installation costs of pre-insulated pipes laid in city centers, in areas with fortified surface, or in areas with a high density of customers.

Table 15. Estimated values specific installation costs of pre-insulated pipes.

Dual-pipe system DN	Specific installation costs [EUR/$m_{pipeline\ length}$]
25	175 – 220
32	185 – 225
40	195 – 240
50	210 – 260
65	230 – 280
80	245 – 300
100	270 – 325
125	305 – 375
150	335 – 415
175	370 – 455
200	400 – 490
250	460 – 565
300	540 – 665
350	590 – 730
400	660 – 805
450	705 – 865
500	755 – 925

Table 16. Estimated values for specific installation costs of pre-insulated pipes laid in city centers, areas with fortified surface or areas with a high density of customers.

Dual-pipe system DN	Specific installation costs [EUR/$m_{pipeline\ length}$]
25	325 – 395
32	340 – 410
40	360 – 440
50	380 – 465
65	405 – 495
80	440 – 530
100	490 – 600
125	550 – 675
150	630 – 765
175	670 – 820
200	740 – 905
250	860 – 1050
300	990 – 1210
350	1115 – 1365
400	1225 – 1500
450	1300 – 1585
500	1390 – 1700
600	1590 – 1955
700	1790 – 2185
800	1910 - 2355

Indirect substations are routinely inspected every 30 months and direct substations (i.e., the connection of the building to the network without heat exchanger) every 20 months. Together with a routine inspection, the heat meters are replaced after every 60-month period. Direct substations must be inspected more often, since certain devices to be used at direct substations (pressure reduction valve, differential pressure valve, safety release valve) are critical for a safe operation.

Pressure control valves and safety release valves, which are installed in direct substations, are replaced every 20 months. These devices are often checked at a workshop and are then again installed in the field to avoid the more expensive on-site check. All the other devices are replaced only when necessary.

6.1.3 Actions To Reduce O&M Costs

The first action to take to reduce operating costs is to reduce energy costs, e.g., by lowering the supply and return water temperatures or by switching from a steam system to a hot water system. (Chapter 7 discusses this in more detail.). This is of special importance if a steam system is installed in parallel to a hot water system so that the conversion to a single system will clearly help reduce O&M costs.

Often, O&M costs are cut down by reducing staff costs, e.g., by increasing the use of remote control systems to control substations or remote metering systems that record energy consumption.

Since maintaining a supply of spare parts can contribute significantly to O&M costs, the stock of standby equipment is often limited to the most important parts (e.g., safety equipment, or parts critical to safe operation like filters, energy meters, maximum flow limiters, pressure control valves, or safety valves).

Last, but not least, a stringent quality control and quality management of both, new construction and repair measures, will help to cut down future O&M costs.

6.1.4 Actions To Reduce Energy Costs

Two types of actions are taken to reduce energy costs in district heating systems in Europe:

1. *Lowering the supply and return water temperatures*
   Many of the district heating systems in Europe are low temperature systems, which have a maximum temperature of 280 °F. Steam district heating systems are being converted to hot water systems for a number of reasons. Lowering the supply and return water temperatures in the distribution pipes has significant energy savings. A system with a supply temperature of 350 °F and a return of 220 °F changed to a low temperature system would reduce distribution heat losses by 60 percent.
2. *Installation of a Combined Heat and Power (CHP) Unit*
   Combined heat and power (CHP) systems offer significant energy savings if the thermal load closely matches an efficient electrical generation rate for the operating equipment. Since a constant thermal load is not possible, additional equipment must be purchased to meet peak values.

6.2 Government Incentives and Taxes in Germany

In the 1960s, the investment and rehabilitation of DH systems with the newest technology (pre insulated plastic jacket pipes) was supported with grants from the federal government. The same situation happened during the refurbishment of DH systems in Eastern Germany during the 1990s. Here some 20 percent of capital costs were paid by the federal budget.

More recently, DH systems only receive direct financial support from public bodies in cases where a district heating network is needed and desired for political reasons, but is not economically feasible. Even considering that trend, there is still substantial support for systems that combine heat and power generation.

6.2.1 Law on Promotion of Combined Heat and Power Production

The production of heat and power in separate plants is significantly less efficient than the combined production of both products in a CHP plant. But the power production in small-sized plants is often more costly than in a large-scale condensing power plant, even one with poor technical performance. To eliminate this relative disadvantage, a system that combines power and heat production may become a candidate for public funding.

6.2.2 Incentives in Detail

In Germany, a number of indirect incentives that support CHP generation are provided to the development of DH systems. Such installations normally require a connected DH system to make use of the generated heat energy. The provided incentives allow the DH system to market heat energy at a substantially lower cost than systems with heat-only boilers. This improves the competitiveness of district heating systems.

The first incentive takes the form of support for smaller CHP generation installations, which receive an additional fee for each kWh delivered to the public grid. The fee paid by the power network operator to the CHP plant operator is reimbursed through the connected customers' electricity bills.

The second incentive supports major CHP installations; those with a firing capacity exceeding 20 MW (68 MBTU) receive a larger amount of CO_2 emission allowances than they have to return based on their annual fuel consumption. The allocation of emission allowances corresponds with their production i.e., both heat and power products are valued in terms of emission allowances as if they had been generated in separate conventional installations. The excess allowances (currently some € 25/t CO2-e) can be sold at the market.

The third incentive operates through the emission trading system in support of CHP units. A number of heat supply installations participate in the European Trading System (ETS) and received emission allowances according to their historical emissions based on fuel use. If the plant lowers emissions during 2005-2007, the excess emission allowances remain with the installation operator for sale or other purposes (current value is some € 25/t CO_2) on the condition that the respective plant is not simply shut down. (The plant must maintain a minimum 60 percent level of production.) This situation supports connection of CHP installations to currently boiler-fed heat supply systems.

Nevertheless the conversion does represent a financial risk since DH networks require substantial capital investment. (Capital expenses amount for some 40 percent of DH supply costs.) Therefore the DH system operator charges customers interested in the connection to a DH network a connection fee. This fee (a maximum 70 percent of reasonable costs according to good practice are allowable) is regulated by general supply conditions issued at federal public level. These general supply conditions

(AVB FernwärmeV) are outlined in a decree issued by the federal government for the implementation of federal law.

Some of the federal states (e.g., Nord Rhine Westphalia) created their own promotion programs to support the investments needed to use waste heat for District Heating from heat and power co generation units, renewable energy sources and waste incineration plants. This includes a support calculated as avoided power network extension costs, due to the decentralized generation of power.

7 Advanced European District Heating Technologies and Concepts

7.1 Low Temperature District Heating Systems

7.1.1 Advantages, Disadvantages, and Requirements for Implementation

Many of the district heating systems in Europe are low temperature systems that have a maximum temperature of 280 °F. Steam district heating systems are being converted to low-med temperature hot water systems for a number of reasons:

- A lower temperature heating medium has less heat loss in the distribution piping system.
- The lower temperature allows the use of polyurethane foam insulation, which has a better insulating value, at a lower cost than other insulation materials.
- The lower temperature also allows the use of a non-metallic conduit, which resists soil corrosion, and is available at a lower cost than comparable metallic conduit.
- The lower temperature results in a system that is easier to control. A warmer temperature fluid contains more heat in a given volume. An increase in flow due to a control valve opening results in a greater amount of heat available. Therefore, controls would tend to cycle more at higher temperatures, making it more difficult to maintain desired conditions.
- The lower temperature allows a lower pressure off the steam turbine that is generating electricity. The lower pressure means a greater pressure drop at the turbine, which allows the turbine to produce more electricity per pound of steam.
- A district heating system that has a low temperature hot water heating fluid is safer than one with a warmer medium. A system with 280 °F hot water must be pressurized to a value that exceeds 35 psig to keep the water from flashing to steam. If there is a leak, the water will escape the piping system in the form of steam. High pressure steam jets are very dangerous in that they are hard to see and can cause serious burns. Low pressure steam leaks are easier to see and their energy dissipates more quickly.

Still, low temperature water systems have some disadvantages. One way to increase the amount of heat available to the users without changing the

piping system is to increase the supply temperature. Low temperature systems have little capability to do this. Also, heat exchangers required at the building interface must be a highly efficient type, most likely a plate-and-frame type with a large surface area. Heat exchange surfaces must remain clean to maintain their high efficiency. If these surfaces become dirty or fouled, the heat exchanger cannot achieve the desired temperatures of the domestic hot water, space temperature, or other needs.

7.1.2 System Design Considerations

To use the PUR type underground pipes, the maximum temperature should not exceed 250 °F, with a return water temperature of 120 °F. This would be the design criteria for the required heat exchangers. System designers must be aware of supply water pressures in laying out the pipe distribution system. Supply water pressures must be maintained between a pressure of 100 psig and 45 psig at the customer's compact station. Pumping stations placed in the piping network may be required to boost pressures when they get too low. The pipe size needs to be selected to minimize pressure losses and to provide quiet system operation. The velocity in the mains should be kept less than 11.5 ft/second. Branch piping should be deigned for a maximum velocity speed of 6.6 ft/second for the flow to the customer and a flow of 3.3 ft/minute in the customer's service connections.

7.1.3 Unique Components and Their Installation Cost

The customer's compact station contains a meter, heat exchangers, valves, controls, and other components needed for the safe transfer of heating energy to the customer. These customer-purchased units are available from the utility or other parties. The cost for a compact station that could service one single-family dwelling is approximately $3,000.

7.1.4 Energy Use Impact

Lowering the supply and return water temperatures in the distribution pipes has a significant energy savings. A system with a supply temperature of 350 °F and a return of 220 °F that was changed to a low temperature system would reduce distribution heat losses by 60 percent.

7.2 Variable Temperature District Heating Systems

7.2.1 Advantages, Disadvantages, and Requirements for Implementation

The variable temperature district heating systems are a low temperature type that further lowers the supply water when demand for heating is less than peak. There is generally no building heating demand in the summer. The only demand for heat from the district heating system is to make domestic hot water or to meet other process heating needs. The supply district heating water temperature can be reduced to a value that satisfies the domestic hot water or process demand, typically to below 200 °F. Later it is raised inversely to the reduction of outside temperature in response to the demand for heating. Advantages to the variable temperature system are:

- lower pipe heat loss
- longer life of the insulation
- less expansion/contraction stress on the distribution pipes.

If the heat is generated by a CHP, the lower hot water temperature allows a greater pressure drop across the turbine generator resulting in producing more electricity.

7.2.2 System Design Considerations

The primary design consideration is identifying how low the temperature can be dropped while satisfying the demand for domestic hot water and/or the needs of other processes. It should be noted that city water temperatures often are warmer in the summer, which reduces the amount of heat needed to raise the water to the desired 140 °F.

7.2.3 Unique Components and Their Installation Cost

The use of a lower district heating temperature will affect the selection of the domestic hot water and process heat exchangers. To operate at a lower temperature, they will need a larger heat exchanger surface. These heat exchangers will cost somewhat more than those purchased when the compact station is being built (that might be selected using the winter peak heating temperature). The only other costs will be for controls to adjust the supply temperature to follow the heating demand based on outside temperature.

7.2.4 Energy Use Impact

A low temperature in the district heating system will result in less heat lost through the piping system.

7.3 Combined Heat and Power Systems

7.3.1 Advantages, Disadvantages, and Requirements for Implementation

A CHP system takes heat that would be normally wasted by an electrical power generating station and uses it for heating purposes. There are two types of CHP stations, which vary in the type of prime mover for the generator, one uses steam driven turbines, and the other uses gas turbines.

In the steam system, "energy waste is the energy lost" when condensing the steam after leaving the turbine so it can be reused as boiler feed water. A typical power boiler creates high pressure superheated steam to drive the turbine. This steam exits the turbine at a pressure based on the condensing temperature. At a pressure of 1.5 inches mercury absolute, 1042 Btu per pound of water must be removed to condense the steam to liquid water. In a CHP system this energy is used for thermal heating purposes and can be sold as a heating commodity. Since the CHP system sells thermal energy, it must be warm enough to be useful. Therefore, the back pressure steam off the turbine is going to be a higher pressure that 1.5 inches mercury. If the temperature required for in the district heating system is 250 °F, the heat exchanger supply steam temperature will need to be approximately 270 °F, which equals a saturated steam pressure of 42 psig. Thus the CHP system uses some of the available steam pressure that would have been used for power generation. A value of 20 percent loss would be common.

The other type CHP unit would have a waste heat boiler through which the combustion gases from the gas turbine flow. The waste heat boiler uses these hot gases to heat water that then is used district heating system. If there is no waste heat boiler, the energy in the combustion gases is mostly lost. This is typically called a combined-cycle plant.

7.3.2 System Design Considerations

The main system design consideration is to match the electrical generation demand with the thermal heating demand. In the United States, electrical demand normally occurs in the summer while the heating peak demand occurs during the winter. Absorption chillers can be used to help satisfy

the summer cooling needs, and to lower the electrical demand. These absorbers use thermal heat to operate and therefore add to the thermal load on the CHP system.

7.3.3 Unique Components and Their Installation Cost

The additional cost elements of a CHP plant compared to a heating plant that is typical to U.S. Army installations are the electrical generation equipment, the electrical switching and power conditioning equipment, and the additional cost of a high pressure boiler, valves, and piping. Thermal storage tanks and absorption chillers are often used to optimize the CHP.

7.3.4 Energy Use Impact

A CHP plant uses approximately 70 percent of the fuel energy. An electrical generating plant can use about 35-40 percent of the fuel energy. Therefore, the CHP has an energy savings compared to the combined energy use of a heating plant plus a power generation plant. The savings are greatest when the heating load can be kept constant so the electrical generation equipment has a steam flow that matches the thermal load. Since a constant thermal load is not possible, additional equipment must be purchased. First, more than one boiler/turbine unit is installed. These units can be cycled to better suit the thermal load profile. Second the thermal load profile can flattened by the use of thermal storage tanks and the use of absorption chillers where cooling is needed. The thermal storage tanks can be used as a depository for hot water during a low thermal load and the stored hot water can be used to satisfy peak hot water demands. The absorption chillers would use the hot water during the cooling season to offset the use of electricity. The cooling season is a time when the thermal loads for heating is minimal and there are normally few other heating demands. The CHP system serving Heidelberg is an example of such a system.

7.3.5 Example Plant – HEC Kraftwerk Heidelberg

An excellent example of a CHP plant is the plant in Heidelberg operated by Harpen Energie Contracting GmbH (HEC) that services the University Clinic Heidelberg INF, the German cancer research institute as well as the newly built technology park. This plant will annually produce 140.000 MWh heat for hot water production and space heating; 13.000 MWh steam for sterilization, kitchen, and laundry needs; and 26.000 MWh cool-

ing energy for air conditioners and coolers. In addition, a recently installed gas turbine will generate electrical power to be sold to the grid.

This plant was originally a heating plant with boilers that serviced the University. In 2000 HEC won a contract to take over the operation of that heating plant. The plant was then modernized by adding a CHP unit that consisted of a gas-fired turbine that powers a 13.5 MW electrical generator. The hot gases off the turbine are fed to a waste heat boiler capable of recovering 20 MW of heating energy. There is a natural gas booster heater in this gas stream that provides an additional 18MW of heating energy. The existing boilers are now used for peak heating situations and for heating backup to the waste heat boiler.

This plant also installed a centralized chilled water cooling system to replace decentralized units located at other locations in the University buildings. Two new absorption chillers at 5MW cooling energy were installed to use the excess heat generated in the summer. There were also three centrifugal compression chillers of the same capacity installed in the central energy plant.

Thermal storage tanks were added to smooth out the heating and cooling loads for a more optimum generation of electrical power. These tanks are used to store hot and chilled water when the building demand is less than the generated amount. When the demand exceeds the rate of generation, hot or chilled water is removed from these tanks to meet the demand. Appendix D includes more information on this CHP plant.

7.4 Biomass Fired Systems

7.4.1 Advantages, Disadvantages, and Requirements for Implementation

The use of waste wood, tree bark and saw mill scrap, burnable trash, and other combustible waste products (collectively called "biomass") as a boiler fuel defers the use of traditional fuels that are in limited supply. Biomass is considered a renewable energy source (one that can be replenished over time). In Europe, power generated using renewable energy sources sells at a premium, and in the United States, LEED/SPiRiT Program points can be obtained for using this type of power resource. Advantages to using biomass include its:

- lower fuel costs
- potential higher selling price for produced power
- use of an renewable resource.

There are several disadvantages to burning biomass fuels. They are often dirty and contain materials that could harm the heating boiler system, and these materials are commonly wet, which reduces their heating value.

7.4.2 System Design Considerations

A waste handling system must be constructed to properly handle the unique properties of the waste materials found in the biomass. Here the waste material would be unloaded from the trucks, railroad cars, or other means of shipment. It would then be screened to remove unwanted materials such as metals, rocks, and other non combustibles. The screen biomass would also be stored here for delivery to the boiler.

To design such a facility, the following are considered: the amount of biomass handled; the means of shipment to the plant; the general knowledge of waste content and size; and the moisture content need to be identified. This will help select the required size of conveyors, separators, and storage silos or areas. Care must be taken to assure the biomass will keep flowing through the system to avoid hot pockets and fires occurring in the stored material.

The waste material needs be evaluated for heat and moisture content. This information is required to properly select the boiler and identify the plant’s size. Samples of all possible sources of the waste material need to be obtained and tested. These tests should also include an evaluation of the pollutants that would be created by burning the biomass. This will help in the design of the air quality control equipment and the ash handling system. Researchers visited a biomass power plant in Ulm, Germany.

7.4.3 Unique Components and Their Installation Cost

The biomass material handling equipment required to properly get the unloaded material to the boiler and the air pollution system are the two unique components.

7.4.4 Energy Use Impact

The burning of a biomass material to generate power saves the traditional energy sources that are not renewable.

7.5 Conversion of Steam District Heating Systems to Hot Water Systems

7.5.1 Advantages, Disadvantages, and Requirements for Implementation

Many of the older district heating systems use steam as the heating medium. Steam was produced in the boilers and because of its pressure movement of the heat through the system was assured. These systems also have a number of problems. They required a lot of maintenance to keep steam traps, condensate receivers, pressure reducing valves and other piping components operating properly. The steam systems required a high degree of water treatment since the open system allows ingress of oxygen, which accelerates corrosion, and impurities in the (boiler) water are concentrated due to water evaporation to make steam. There is also a safety concern with the use of steam. High pressure stream leaking from a pipe or vessels can be invisible and can cause serious burns. Also surfaces of objects that contain steam are normally very hot and can cause burns if touched.

Because of these difficulties new heating systems have turned to hot water as the heating medium. Even some of the older steam systems are being converted to hot water distribution systems. The city of ULM, Germany is one such location. Hot water systems offer a number of advantages:

- They are easier to control. With hot water the temperature and the flow can be adjusted. With steam the pressure determines the temperature and it's difficult to vary the pressure leaving only the flow as a way to change the rate of heating.
- They require less maintenance.
- They are safer.
- They are less prone to leak.
- Their distribution piping systems last longer.

The major issue with this modification is the transformation of the steam distribution system to the hot water system. Since steam is a vapor it needs a large pipe for its movement. The steam carries much more heat per pound than a typical hot water system. Therefore, the steam system accommodates less water mass than a hot water system. As the result, the condensate pipe for the steam system is undersized for the return hot water system. The condensate pipe also has a higher likelihood to corrode and may need to be replaced. In many instances, switching from steam to hot water requires a new return water line, although the steam system supply line can usually be reused.

Another element of the distribution system that must be changes is the customer heat transfer station. The steam heat exchangers, flow meter and valves all must be replaced with new components compatible with hot water service.

A hot water system requires pumps to achieve the water movement. Often there needs to be booster pumps located throughout the distribution to maintain the water pressures in the proper range.

7.5.2 System Design Considerations

Design considerations of switching from steam to hot water include the heat exchange needs at the heating plant and each of the buildings being serviced. The routing of the hot water pipe also causes design issues. New heat exchangers will be required at both ends of the piping system. Temperature requirements need to be identified for their selection. Pumps will need to be located and sized. As stated there is a safe maximum pressure the building piping components can handle. There is also a minimum pressure needed to move the hot water through the pipe system to the buildings being serviced and back again. This acceptable pressure range may require building substations throughout the piping system where additional booster pumps can be located. It is recommended that the entire piping system be modeled through the use of a piping computer program to better understand the dynamics of the piping system as building demands are being met.

Modeling the proposed system will help the designer to develop a good understanding of the water flows. The model will help determine the amount of new pipe needed to achieve the required return water flow. Much of the existing condensate pipe will be reused (assuming it has a reasonable life remaining). Maximum return water flows in the existing condensate pipe are programmed into the model. This model will identify where there are flow restrictions of the existing piping system. At these locations new pipe will be installed to relieve the restriction. Slightly higher pressures and speeds of flow will be acceptable in the new piping system design to enable the new system to use as much as the existing condensate piping as possible. In relieving restrictions, a new main pipe may be installed parallel to the existing return water main or a totally new pipe to carry the total return water will be added.

Other concerns include locations for meters to monitor the amount of energy being consumed, water treatment and filtering of the hot water, pro-

visions for maintenance of low return water temperatures, and the identification of leaks and other maintenance requirements.

7.5.3 Unique Components and Their Installation Cost

The customer's compact station that contains all the devices to meter flow and transfer the heating energy is one of the unique elements of this system. It can be purchased from the utility or other parties at a cost of approximately $3,000 for a unit that would service a typical residence.

Other unique components include the underground pipe, pumps and temperature controls. The cost of these devices will depend on the unit size and their sophistication.

7.5.4 Energy Use Impact

The hot water distribution system will have less energy waste since there will be significantly fewer leaks and lower heat loss when a lower temperature media can be used. With the lower temperature media there can be a greater pressure drop across the turbine on CHP plants allowing more electrical production.

7.6 ThermoNet/ECONET Heating and Heat Recovery Systems

In Finnish DH systems, the normal temperature of supply hot water varies from 65 to 115 °C and the return water temperature is normally in the range of 40 to 60 °C. Typically, each building connected to the DH system has a substation where the quantity of hot water used is metered and where heat exchangers, pumps, and controls for distributing the heat throughout the building are located. This substation is similar to the ones used in Germany except the type called "ECONET."

ThermoNet/ECONET heating systems are packaged liquid-coupled heat recovery systems used by the FläktWoods company for building heating and cooling. The can be used in combination with DH systems, solar energy, ground water, and other heat sources. These systems combine heat recovery in the HVAC system with the flow used to heat and/or cool the air. With the use of larger heat transfer areas, lower temperature levels can be used to heat the air. Since the flow through the heating and cooling coils are integrated with the heat recovery coils, there are fewer pumps and valves, and less piping is required. This integration makes for a smaller,

more compact unit, and also improves heat recovery by 15 to 20 percent compared to the traditional run-around-coil systems.

The ECONET system reduces the DH return temperature and the total water flow during peak heating periods. A reduction of 15 to 20 °C is common when compared to traditional systems. This improves the efficiency of generating electrical power in the CHP plants. The lower fluid flow reduces the pumping energy required to circulate the heating fluid through the DH system.

Some systems use the DH fluid directly in the buildings heating system without the use of heat exchangers. This provides a better use of the incoming temperature and results in a lower return temperature. The building's (potable) domestic hot water systems must be isolated from the DH fluid. At times the heating system is combined with a chilled water system and a three pipe distribution system is used. One pipe is the hot water supply, another pipe is the chilled water supply, and the third pipe is a common return pipe. At the buildings HVAC units there is a large temperature change across the heating and cooling coils as well as heat recovery that takes place. The result is a return temperature that fully uses the heating and cooling energy delivered.

Appendix D, Sections 3 through 6, give more information on the ThermoNet/ECONET heating systems.

8 Application of European District Heating System Technologies in the United States and on Army Installations

8.1 Issues that Affect Application of DH Systems in the United States

8.1.1 Load Densities

The concept of a viable DH system depends two critical factors. The first is the density of the heating loads. Load densities in the range of 0.7 to 1 MBtu/hr/acre are required for systems to be viable. In Europe, the pattern of urban development differs from that in the United States, where cities tend to be very dense with medium rise residential buildings. The transition to low density development is fairly abrupt at city edges. The second critical factor is a willingness to consider integrated resource planning and accept centralized approaches. In Europe, where nations are social democracies, there is an acceptance of centralized planning and resource use. Many of the city works supply all the utilities and there is an incentive to do things more efficiently. In the United States, cities tend to grow through "urban sprawl," and to construct themselves as dense central business area surrounded by low density suburbs and strip malls. Suburban energy densities are well below half the required amount. The type of development and density of loads along with a desire and ability to conduct business on a centralized basis are both crucial to implementation of district heating systems. In the United States both are generally lacking.

8.1.2 Climate

Another aspect where Europe differs from the United States is climate. Most of Northern Europe is a heating only climate where most of the United States is at lower latitudes with a temperate climate requiring both heating and cooling. This requires either the distribution of chilled water along with hot water or the addition of an absorption chiller to the building HVAC systems.

8.1.3 Utility Industry

It will be more challenging to implement district heating in the United States than it has been in Europe because U.S. electric utilities express less interest in cogeneration or becoming involved in the heating business than

their European counterparts. Deregulation of the electrical systems without the past vertical integration also makes the concept more difficult to apply. For U.S. municipalities, central energy planning is a foreign concept. Municipalities do not generally supply heat or electricity. These services are left to either the utility industry, who have few interests in centralized planning, or to the private sector, which tends to focus its efforts on achieving short term gains, has high discount rates, and eschews holistic thinking.

8.2 Considerations for Application of District Heating and Cooling Systems on U.S. Army Facilities

In the United States, implementation of district heating and cooling technology has grown on college campuses, eco-industrial parks, and medical complexes. These locations all share the high energy density that optimizes the technology's efficiency and cost effectiveness. Also, technology has changed with the advent of smaller gas turbines. The new emphasis in district energy is to use plants that supply hot water or steam, chilled water, and electricity (tri-generation). They also tend to be multi-fueled. Some utilities are now building some of these district energy plants and selling the steam and chilled water to a co-located campus type entity.

Most CONUS Army installations also exhibit high energy density, and thus can take advantage of the efficiency and cost effectiveness of the modern DH heating and cooling system. The Army Energy Program seeks to meet the requirements of EO 13123* and the Energy Policy Act of 2005. These requirements include reducing facility energy 2 percent per year from 2006 through 2015 using FY 2003 as the baseline. Modern DH systems offer significant opportunities to meet or exceed these requirements by reducing waste and inefficiencies in the operation of energy plants and reducing energy losses in distribution systems.

8.2.1 First Costs

Meeting energy consideration goals will require the Army to continue to make investments to modernize its infrastructure on installations in the CONUS. Part of this is being accomplished by privatizing the utility systems on the installations and having the new owner modernize and upgrade them. This paradigm has been applied to all utilities except for cen-

* Executive Order 13123—Greening the Government Through Efficient Energy Management (8 June 1999). Presidential Documents. Federal Register. Vol. 64, No. 109. 30852-30860.

tral plants supplying heating and cooling and their distribution systems. The common belief within the Army is that this sector cannot be privatized and the approaches used in Europe do not apply in the CONUS. In a way this is true because in Europe all the contracts were signed with utilities and treated as utilities contracts, not third party contracts. These utilities, in most cases the local City Works, had the desire to increase their loads to make their systems more technically and economically viable. Also they were susceptible to political pressure to make it happen as the mayors did not want new large coal-fired plants built at nearby military installations. So, in some ways the European experience was unique since installations in the United States do have fuel flexibility and little opportunity to partner with cities—though this option has been explored very little by the Army.

A second part of the program is to modernize the buildings through the use of Energy Savings Performance Contracts (ESPC) and other alternative financing approaches. The remaining technical part of the Energy Program is to ensure new buildings are energy efficient. EPAct 2005 requires new federal buildings to use 30 percent less energy than ASHRAE Standard 90.1-2004 requirements.

The military is capable of implementing a new approach to installation energy. A new paradigm that incorporates energy security, fuel flexibility, and the use of modern, efficient district heat and distributed energy technologies should be implemented. The approach should use a combination of third party based and Federal government funds with a view to the upcoming fuel availability and cost issues. Several firms in the United States are in the business of financing, building, and operating district energy systems. The potential is tremendous for the U.S. Army to save energy, become more fuel flexible, and enhance energy security by providing most of their electrical needs by on-site or nearby generation facilities. These facilities could supply hot and chilled water along with the power. Low temperature systems using direct burial techniques should replace older, failing systems. A transition away from steam is also recommended where possible.

As the Army transforms and base realignments occur, central energy planning should be incorporated. The U.S. Army should investigate the possibility of either third parties or local utilities constructing district energy plants either near the installation boundary or on the installation itself. Concepts of poly-generation and coal gasification should also be part of

the conceptual planning. Master Planning should consider the energy implications of how installations are developing as they modernize and transform. Design for effective load density should be part of the master planning process to enable effective district energy techniques in the future.

8.2.2 Maintenance Costs

Other than the first cost one of the major issues with district heating systems is the maintenance and life of the underground piping system. Currently used steam and high-temperature hot water systems requires a steel-jacketed pipe covers the insulated steel carrier pipe. The steel outer pipe is coated for corrosion protection, but the joints are very difficult to seal. As the result it normally is not too long before leaks begin to appear in this system. This ruins the insulation and accelerates failures in both the jacket and carrier pipe. In some soils the corrosion rate is increased by a natural electron flow from the pipe to moist soils. A cathodic system can be insulated to minimize this corrosion activity. The result is a piping system that develops leaks after a few years of service. The leaks are hard to find and the repair is quite expensive. Operating with leaks causes excessive make-up water treatment costs in addition to the lost energy.

A high temperature hot water system requires less expensive pipes than do steam systems. In Europe the common underground pipe used in district heating systems has a polyurethane (PUR) foam insulation surrounding a steel carrier pipe all covered with a high density polyurethane (HDPE) jacket. This jacket does not corrode and makes it easy to seal pipe joints in the field. This pipe system also uses a polyurethane foam insulation due to its high insulating value and rigid structure. Well maintained systems are thought to have a useful life of over 70 years.

The use of PUR insulation results in a maximum temperature of 155 °C (311 °F) for the fluid being handled. In general practice, a maximum temperature of 140 °C (284 °F) is used for this type of pipe since the foam deteriorates more quickly at hotter temperatures. Table 17 lists the dimensions of (brand name) Isoplus pipes as compared to U.S. pipes.

Table 17. U.S. insulated pipe characteristics.

U.S. Pipe Size (in.)	Carrier Pipe Thickness Sch 40 (in.)	Insulation, Thickness Ferro-Therm (in.)	Insulation Thickness Ht – 406 (in.)
1	0.133	1.89	2.52
1.5	0.145	1.6	3.24
2	0.154	1.35	3
2.5	0.203	1.75	2.75
3	0.216	1.36	2.44
4	0.237	1.94	3.03
5	0.258	1.95	
6	0.28	1.95	2.95
8	0.322	1.95	2.55
10	0.365	1.48	2.47
12	0.406	1.47	2.51
14	0.438		
16	0.5	1.86	2.85
18	0.562	1.85	2.92
20	0.594	1.91	3.83

Another concern with maintaining a long service life with these pipes is keeping them dry. If the foam insulation gets wet, its composition weakens and the adhesion to the carrier pipe is threatened. Hence the HDPE jacket most be fabricated correctly to assure a waterproof covering. Over time, leaks can develop; thus installing a leak detection system in the insulation has merit. The most common type uses wire placed in the insulation. Any moisture will conduct electricity, which will create a short circuit in a segment of the system. A special monitoring device is used to locate the short circuit (and thus the pipe leak).

Similar pipes are manufactured in the United States. One of the three major pipe producers is Thermacor located in Fort Worth, TX. Table 18 lists dimensions of two of their foam insulated piping systems.

Table 18. European insulated pipe characteristics.

Metric Pipe Size (nom. dia.)	Carrier Pipe Thickness (mm)	Carrier Pipe Thickness (in.)	Isoplus Insulation Thickness (mm)	Isoplus Insulation Thickness (in.)
25	0.102	0.102	32.5	1.280
40	0.102	0.102	35	1.378
50	0.114	0.114	37.5	1.476
65	0.114	0.114	37.5	1.476
80	0.126	0.126	40	1.575

Metric Pipe Size (nom. dia.)	Carrier Pipe Thickness (mm)	Carrier Pipe Thickness (in.)	Isoplus Insulation Thickness (mm)	Isoplus Insulation Thickness (in.)
100	0.142	0.142	50	1.969
125	0.142	0.142	50	1.969
150	0.157	0.157	50	1.969
200	0.177	0.177	57.5	2.264
250	0.197	0.197	75	2.953
300	0.220	0.220	75	2.953
350	0.220	0.220	75	2.953
400	0.248	0.248	80	3.150
450	0.248	0.248	90	3.543
500	0.248	0.248	85	3.346

Thermacor underground pipes can provide:

- *Ferro-Therm* has a steel carrier pipe with a polyurethane foam insulation covered by a HDPE or Type 1, Class 1 PVC jacket. It has a maximum temperature rating of 250 °F.
- *HT-406* has a steel carrier pipe with a high temperature polyisocyanurate foam insulation covered by a HDPE or Type 1, Class 1 PVC jacket. It has a maximum temperature rating of 406 °F.
- *Spiral-Therm* has a steel carrier pipe with a high temperature, polyisocyanurate or polyurethane, foam insulation covered by an aluminum, galvanized, or stainless steel jacket. Its maximum temperature rating depends on the type foam insulation used.
- *Class "A"* steel carrier pipe with a mineral wool, foam glass, fiber glass, or calcium silicate insulation covered by a steel conduit with a corrosion resistant coating. It has a 700 °F maximum temperature rating.
- *Duo-Therm "505"* has a steel carrier pipe with a mineral wool, foam glass, fiber glass, or calcium silicate insulation covered by a steel conduit, which has a polyurethane foam insulation covered by a HDPE jacket. The pipe system has an empty cavity between the inner insulation covering and the steel conduit, which allows this part of the system to drain if it gets wet. It has a maximum temperature rating of 700 °F.

8.2.3 Leak Detection

All piping systems use loops, anchors and expansion elbows for expansion & contraction of the pipe system. Joints are welded and insulated. Electronic leak detection systems similar to those used in Europe are available for all piping systems. It consists of a bare copper wire embedded in the insulation.

The insulating value (Btu/hr/sq ft/°F/in thickness) of the polyurethane is much better than some of the more traditional pipe insulation materials such as mineral wool and foam glass. The data in Table 19 show that polyurethane has an insulation value half that of mineral wool.

Table 19. Insulation values of various insulation products.

Insulation Material	Insulation Value – Btu/hr/sq ft/°F/in thickness
Polyisocyanurate foam	14
Polyurethane foam	14
Fiberglass board	25
Mineral wool	26
Calcium Silicate	32
Foam glass	40

The evaluation of the various pipe insulation materials has shown the foam insulated systems have a better insulating value than the traditional insulating materials. The HPPE jacket also provides a better outer covering since it is more leak proof. When considering cost the foam insulated pipes also are more attractive than a steel jacketed pipe (FBE Class A). Table 20 lists the budget cost from the pipe manufacturer Thermacor Process, LP for 1 ½-in., 3-in., 6-in., and 12-in. (schedule 40 ERW steel) pipe using various insulation materials. The PUR type pipe components are the least costly, less than half the cost of traditional insulated piping. The cost of higher temperature HT 406 piping components are a little more than half that of traditional piping.

Table 20. Budget cost of representative pipe sizes in the United States.

Pipe Size (in.)	FerroTherm Insulation Thickness (in.)	HDPE Cost	HT 406 Insulation Thickness (in.)	Cost	FBE Class A Insulation Thickness (in.)	Cost	Duo-Therm Insulation Thickness (in.)	505 Cost
1.5	1.6	$11.55	3.2	$23.39	2	$46.99		
3	2.4	$16.66	2.4	$23.39	2	$55.93	1.5-in. & 1.9-in.	$49.50
6	2.9	$29.42	2.9	$42.55	3	$80.69	2-in. & 1.5-in.	$71.55
12	1.5	$56.81	2.5	$76.40	33.5	$132.48	2.5-in. & 1.9-in.	$136.32

Both of these piping systems have a leak detection system that monitors the dryness of the insulation. Should a leak develop and the insulation become wet the leak detection system sounds an alarm. The location of the leak can be identified using a Time Domain Reflectometer instrument. The cost of this system is approximately $0.10/ft. The leak detection is accomplished by having a bare copper wire that is embedded in the foam insulation, which is a very poor conductor of electricity when dry. The resistance to electrical current flow between the carrier pipe and the copper wire is continuously measured by an ohmmeter. Should moisture enter the foam insulation, the resistance to electrical current flow has a dramatic drop, which is determined by the ohmmeter. This is similar to an electrical short in the electrical wiring system. The location of the electrical short can be identified by the Time Domain Reflectometer. A minimum amount of pipe needs to be unearthed to determine the leak cause and implement the necessary repair.

Often the copper comes standard with the straight runs of insulated pipe. At field joints, the copper wire leads need to be connected using an insulated jumper wire crimped to the two ends. Thus a continuous copper wire is created in the foam insulation. The result is an inexpensive sensitive leak detection for the piping system.

Most of the larger Army systems use either steam or high temperature hot water as the heating medium. The heating piping systems normally found at U.S. Army installations typically use mineral wool, fiberglass, calcium silicate, or foam glass as insulation (rather than polyurethane foam). The maximum temperature limit for the polyurethane foam is 250 °F, which equates to 15 psig steam—too low a pressure to distribute steam over any useful distance. Even at the 280 °F temperature limit used in Europe, which corresponds with 34 psig steam, the resultant pressure is too low for a district heating system. The polyisocyanurate foam has a maximum temperature of 406 °F, which is the temperature of 250 psig steam, which is well above the normal steam pressure found in site distribution systems.

If the site heating system is a hot water type, it probably delivers hot water above 300 °F. This is again too hot for the polyurethane foam insulation. The temperature could be reduced, but several other concerns would need to be addressed. First, are the distribution pipes big enough to convey the needed heating energy? The buildings being served remove heat from the water to satisfy their needs. The temperature difference of the supply and

return water, times the quantity of hot water flow, defines the heat removed. Lowering the supply water temperature reduces the available heat if the return water temperature and flow rate are unchanged. To keep the same flow rate, the return water temperature would also need to be reduced. This leads to the second concern—the heat exchanger components must be able to extract adequate heat from the cooler water. It is expected these heat exchangers would need to be replaced with larger more efficient ones. These new heat exchangers could be sized to also return lower temperature water thus allowing a flow similar to the original to be required. If the flow does not change, then the distribution pipe should be an adequate size. The piping system size would need to be investigated if more hot water flow is required to deliver the required heat to the buildings.

In making a change to supply water below 250 °F the heating systems in the buildings would need to be evaluated. They must be compatible with this lower temperature. If steam is required for any of the heating systems, an alternative to that system would need to be found. This may require the installation of new coils in air handling units, new perimeter heating fixtures, or new cooking equipment in the kitchen. If an alternative system cannot be identified, then a small package boiler to furnish the required steam would be needed. If the heating systems were designed for higher supply water temperatures, their capability to continue to perform well would need to be evaluated. Heating coils, radiators, and process needs such as drying ovens, hot water tanks, etc. would need to be analyzed to determine if the cooler hot water would still deliver enough heat for proper operation. Those systems or devices that cannot continue to perform may need to be replaced or modified to use the cooler hot water temperatures.

8.3 Potential for Combined Heat and Power Systems

CHP systems offer significant energy savings if the thermal load closely matches an efficient electrical generation rate for the operating equipment. U.S. Army installations have cantonment areas where the building density is enough to make the installation of heating and cooling distribution piping cost effective. These posts also have a significant thermal heating demand throughout the year making them attractive candidates for a CHP system. Currently there are no significant CHP plants operating at Army posts. There has been a reluctance to undertake the responsibility of power generation since the need can be satisfied by local utilities. But the rising cost of energy, the need to modernize central heating plants, and increased attention to energy security make the application of CHP systems an attractive alternative that should be evaluated.

However, several barriers to the application of CHP systems at Army installations are:

- The existing heating boilers do not produce the high pressure steam required for efficient generation of electricity.
- Absorption chillers would be needed to enhance the summertime thermal load so that year-round electrical generation would be attractive. Thermal storage systems may also be required.
- Current CHP personnel probably do not have the training to operate and maintain electrical generation equipment.
- Current fuels used on Army posts are typically natural gas and fuel oil. Coal may be the choice for the CHP plant requiring new and amended contracts to purchase the desired energy source, and environmental permitting changes.
- For some electrical contracts, several Army posts are grouped together for a utility wide rate schedule. A new rate schedule would be required with the addition of a CHP plant.

The construction of new CHP systems would be a very costly undertaking. It would require a multi year commitment to assure construction of the total system and its proper maintenance throughout its life. A commitment of this type might be better ensured through the use of a third party owned CHP plant that sells the thermal electrical energy to the Army installation.

8.4 Comparison of Centralized to Decentralized Heating Plants Applied to U.S. Army Installations

The typical system heating systems constructed in the past 30 years are designed to serve individual or small groups of buildings. These decentralized heating plants generally used natural gas as their fuel because it is a simple delivery system, low environmental emissions and reasonable cost. Recently the cost of natural gas has increased significantly. Also the maintenance personnel on the installations have been reduced over the years while the maintenance needs of the decentralized equipment have increased. There are control issues with decentralized equipment and each unit has more components when compared with equipment that receives heating and cooling energy from a central plant.

Today's central heating systems are efficient, reliable, and provide flexibility of fuel choice. The low temperature heating distribution systems avoid many of the problems associated with steam and high temperature distri-

bution system. They can be constructed to burn coal, oil, natural gas, or even biomass—whichever is the most competitive.

If the existing decentralized equipment is over 20 years old and approaching the end of its useful life, an evaluation of a centralized system to replace the old equipment is recommended. This evaluation would assess the unique issues and circumstances of the situation. The cost of upgrading the existing heating system could be used to support the cost of the central system. The issue of fuel availability could be addressed. Problems of installing new underground pipes could be clarified and properly reflected in the central heating system cost. If there are maintenance concerns, they could be addressed as well.

9 Conclusions and Recommendations

9.1 Conclusions

9.1.1 European DH and CHP Systems

This study has investigated and evaluated modern DH systems in Europe, focusing on experiences with these systems on U.S. Army installations and municipal systems in Germany and Finland. This included an evaluation of the feasibility and economics of converting existing steam systems to hot water systems to medium or low sliding-temperature systems to reduce heat and water losses, improve thermal efficiencies, and to reduce the cost of pipe replacement. This results of this study can be summarized as follows:

1. *Operational Efficiency*. The typical European DH system operates as a co-generation system that provides both electricity and heat to its customers with a plant efficiency in the range of 70 to 80 percent, about double that of a modern electrical generation plant (~40 percent).
2. *Common Conversion from Steam to Hot-Water Medium*. Many district heating systems that use steam as the heating medium are converting to hot water systems (medium or low sliding temperature). Hot water heating is a safer medium that allows the use of less costly piping with superior insulating properties, built-in leak detection systems, and low maintenance costs. Additionally, the lower temperature hot water improves the electrical generation capability.
3. *Low Operating Costs*. In some cases, the use of improved monitoring and control equipment successfully reduced the central energy plant labor force. Remote satellite plants are typically unmanned; one operator at the central control station monitors the remote equipment. Other than for maintenance, staff need only visit the remote sites every 1 to 3 days to observe the equipment performance. A shift crew of four to five workers commonly runs large (300 to 600 MW) power plants that once required a crew of 20 or more.
4. *Summer Operations*. If the summer heat load is sufficient at an installation, the use of a CHP system rather than a heating-only power plant:
   a. Reduces the use of energy resources since CHPs are highly energy efficient
   b. Improves energy security due to on-site electrical generation and the use of abundant fuels, *but*

c. Requires a high pressure boiler for the electrical generation (perhaps higher pressure than currently installed), steam turbines, electrical generators, and electrical power conditioning equipment
d. Requires additional training for operating personnel to acquire skills for good performance of the electrical equipment
e. Requires increased O&M cost at the plant (for the new equipment) while lowering the amount of electrical energy purchased.

9.1.2 Application of DH System in the United States

The concept of a viable DH system depends two critical factors: (1) the density of the heating loads (load densities in the range of 0.7 to 1 MBtu/hr/acre are required for systems to be viable.), and (2) a willingness to consider integrated resource planning and accept centralized approaches.

Most CONUS Army installations exhibit sufficient high energy density to reap the benefits of the efficiency and cost effectiveness of the modern DH heating and cooling systems. It may be more challenging to implement district heating in the United States than it has been in Europe because U.S. electric utilities express less interest in cogeneration or becoming involved in the heating business than their European counterparts.

Most of the United States is characterized by a temperate climate that requires both heating and cooling. This requires either the distribution of chilled water along with hot water or the addition of an absorption chiller to the building HVAC systems.

9.2 Recommendations

It is recommended that the Army consider conversion of existing to modern DH systems, which offers significant opportunities to meet or exceed the requirements of EO 13123 and the Energy Policy Act of 2005 by reducing waste and inefficiencies in the operation of energy plants and reducing energy losses in distribution systems.

The Army should consider converting to District Heating systems as part of current efforts to modernize the infrastructure on Army installations in the CONUS; central energy planning should be incorporated as part of such efforts as the Army Transformation and base realignment. Part of this is already being accomplished by privatizing the utility systems on the installations such that the new owner is responsible for modernizing and

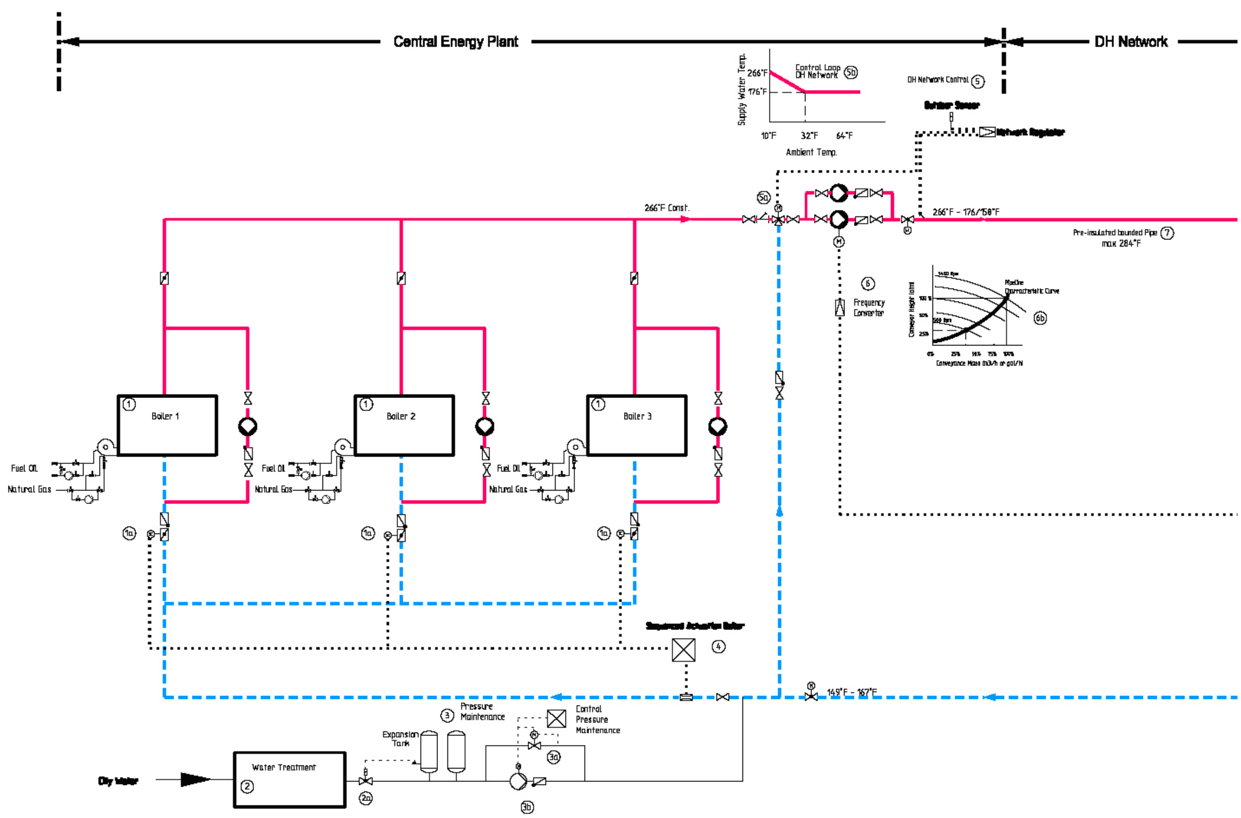
upgrading the system. This paradigm should be extended to include central plants supplying heating and cooling, and to their distribution systems.

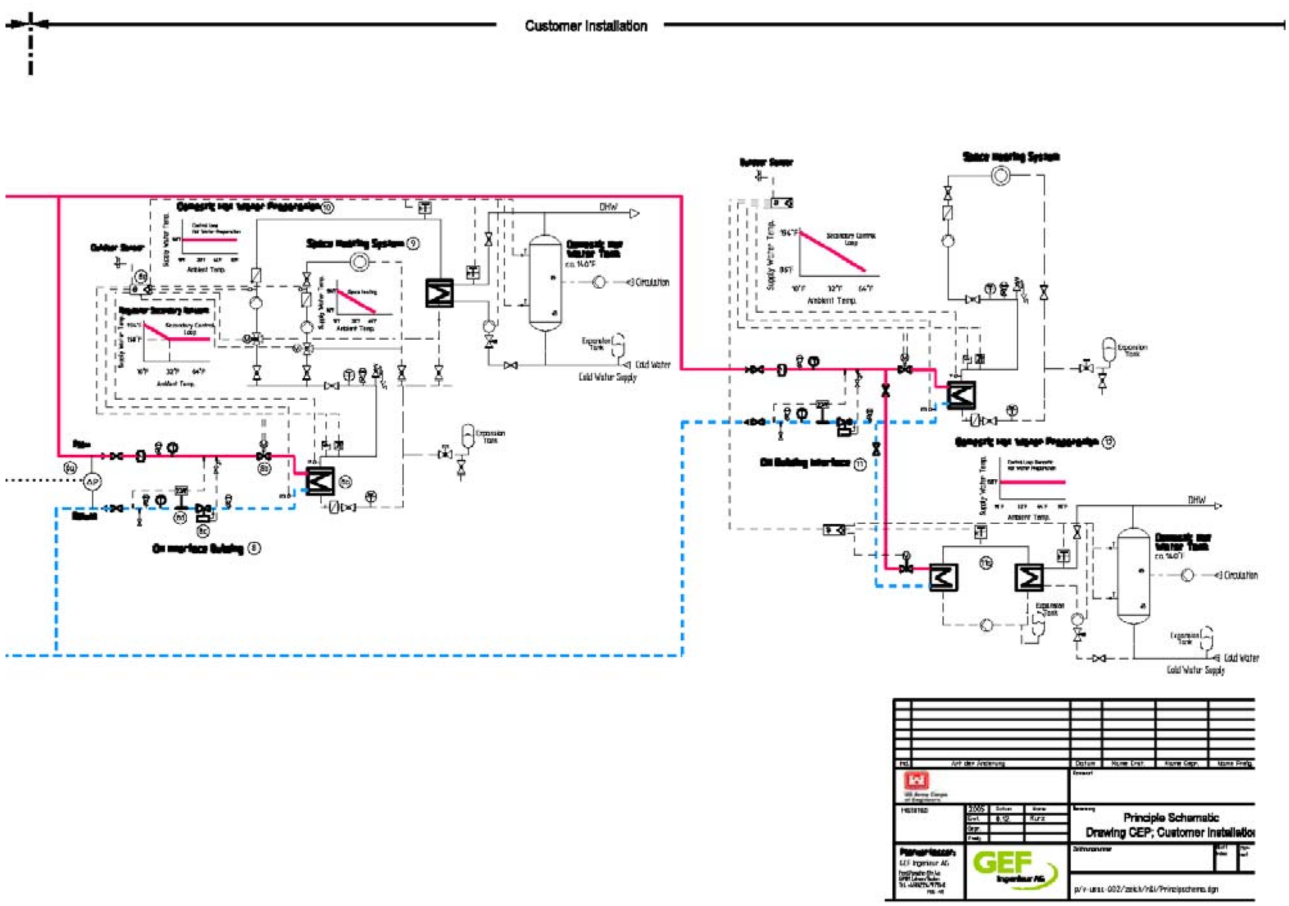
It is recommended that this be achieved with a combination of third party-based and Federal government funds to overcome fuel availability and cost issues, to achieve the potential to save energy, to become more fuel flexible, and to enhance energy security by providing most of their electrical needs by on-site or nearby generation facilities. These facilities could supply hot and chilled water as well as electrical power. A transition away from steam is also recommended where possible; low temperature systems using direct burial techniques should replace older, failing systems. Such plans should consider such advanced concepts as poly-generation and coal gasification.

Modern central heating systems are efficient, reliable, and provide flexibility of fuel choice. The low temperature heating distribution systems avoid many of the problems associated with steam and high temperature distribution system. They can be constructed to burn coal, oil, natural gas, or even biomass—whichever is the most competitive. It is recommended that the Army investigate the application of CHP systems on CONUS installations to overcome the rising cost of energy, to meet the requirements to modernize central heating plants, and to achieve energy security.

Specifically, when existing decentralized equipment is over 20 years old (approaching the end of its useful life), the Army should evaluate whether to replace the old equipment with a centralized system. A costly commitment of this type should involve a third party owned CHP plant that sells the thermal electrical energy to the Army installation as a multi year commitment to assure construction of the total system and its proper maintenance throughout its life. It is also recommended that the Army consider hot water systems instead of steam to take advantage of modern low-heat piping systems, which have low maintenance costs and advanced leak detection.

Appendix A: District Heating System Diagram


Central Energy Plant
DH Network
Supply Water Temp.
266°F
176°F
Control Loop DH Network 5b
10°F
32°F
64°F
Ambient Temp.
DH Network Control 5
266°F Const.
5a
266°F - 176/158°F
Pre-insulated bounded Pipe 7
max. 284°F
6
Frequency Convertor
Machine Characteristic Curve
6b
Boiler 1
Boiler 2
Boiler 3
Fuel Oil
Natural Gas
1a
4
149°F - 167°F
3 Pressure Maintenance
Control Pressure Maintenance
Expansion Tank
3a
3b
Water Treatment
2
2a



Customer Installation
Space Heating System
DHW
Circulation
Cold Water Supply
Expansion Tank
Ambient Temp.
Supply Water Temp.
Secondary Control Loop
Principle Schematic
Drawing CEP; Customer Installation
GEF Ingenieur AG

Appendix B: District Heating Application Report

DISTRICT HEATING APPLICATION REPORT

Berlin, January 2006

DISTRICT HEATING APPLICATION REPORT

delivered to

USA Ventilation / Energy Applications, PLLC

3087 Glengrove Drive, Rochester Hills, MI 48309, USA

by

MVV Energie, Luisenring 49, D-68159 Mannheim, Germany

Contact: Dr. Jörg Matthies, j.matthies@mvv-consulting.com

Berlin, January 2006

Contents

The Mannheim DH System

General Information

District Heating System Name

The considered district heating system is called the Mannheim district heating system.

Location

The system supplies the cities of Mannheim, Brühl, Schwetzingen, Oftersheim and also parts of the city of Heidelberg.

Mannheim is situated in the South-West of Germany on the banks of Rhine river. It is the second largest city in the federal state of Baden-Württemberg and has some 320,000 inhabitants. The city is heavily industrialised.

Type of Buildings Served

The spectrum of supplied buildings ranges from single family homes up to multi-story-buildings and major commercial and industrial customers. The U.S. Army Garrison Mannheim is also supplied by Mannheim's district heating system.

Number of Buildings and Total Area Served

11,800 customers are connected to the district heating system of Mannheim. The connected heat load amounts to 2,135 MW_{th} (= 7,285 MBTU/h). The district heating network covers an area of approximately 40 km^2.

Supply and Return Temperatures

The heat carrier used is hot water. The maximum supply temperature amounts to 130 °C (266 °F) in winter; in summertime the minimum supply temperature is 90 °C (194 °F). The spectrum of return temperatures ranges from 50 °C (122 °F) up to 65 °C (149 °F).

Heat Generating Systems

Number and Size of Boilers

Mannheim's largest power plant (Großkraftwerk Mannheim – GKM) is the district heating system's main heat source. The heat and power (CHP) plant is situated in the southern part of the city on the banks of the Rhine river. The GKM burns hard coal arriving by ship via the Rhine river and by train. The heat and power plant covers the heat demand of connected customers in Mannheim, Heidelberg and Schwetzingen.

Main objective of the GKM's operation is power generation. The total power capacity installed amounts to 2,100 MW_{el}.

Besides power the GKM generates heat energy for the district heating system by steam extraction from two backpressure-extraction turbines at different pressure levels. Two additional steam-water heat exchangers allow for covering peak consumption.

The GKM sells heat energy to MVV Energie AG company, the municipal utility serving Mannheim. MVV Energie is the owner of the connected district heating (DH) network and distributes and sells the heat energy inside the city.

Peak loads of the heating system's customers in Mannheim that cannot be covered by the GKM are covered by two peak heating plants that belong to MVV Energie. Some more peak heating plants are installed in Heidelberg and are being operated by the Heidelberg energy company.

Type of Fuel(s)

The fuel used in the GKM power plant is hard coal. The peak heating plants in Mannheim are fired with light fuel oil.

Maximum Load

The maximum thermal load of the whole Mannheim district heating system amounts to 1,000 MW_{th} (3,412 MBTU/h). This amount can usually be delivered by the GKM heat and power plant.

Annual Energy Consumption

The annual heat consumption covered by Mannheim's district heating system is about 2,700,000 MWh/a (9,212,800 MBTU/a).

Generated Fluid

The heat carrier is hot water.

Pressure and Temperature

The supply pressure provided by the GKM CHP plant is 9.8 bar (142 psi). The pressure in the return pipe at the power plant's inlet is 0.5 bar (7 psi). The design pressure of the district heating network is 16 bar (232 psi). The supply temperature provided varies between 90 °C (194 °F) in summer and 130 °C (266 °F) during winter depending on outdoor temperature.

Number of Employees

In 2004 the GKM power plant had a staff of 607 employees. This does not include staff engaged with heat transport and distribution that is provided by MVV Energie.

MVV Energie has its own personnel managing the supply of electricity, heat, gas and water of Mannheim from MVV Energie's control and dispatching room. One shift member is responsible for central operations in the heat supply system.

Steam-Driven Turbines

The major amount of the annual heat energy delivered to Mannheim's district heating network is generated in steam turbines in combined heat and power co-generation mode (Figure B1). Steam is extracted from the turbines at two pressure levels (0.3 bar and 1.2 bar resp. 4.4 and 17.4 psi) and is condensed in heat exchangers heating up the district heating water. The turbines cover heat loads of up to 600 MW_{th} (2,050 MBTU/h) and permit a supply temperature of 100 °C (212 °F).

The peak heat generation needed during the winter period is maintained by additional heat exchangers operating with steam taken from the 20 bar steam header. This additional heat input allows for supply temperatures of up to 130 °C (266 °F) to the DH network.

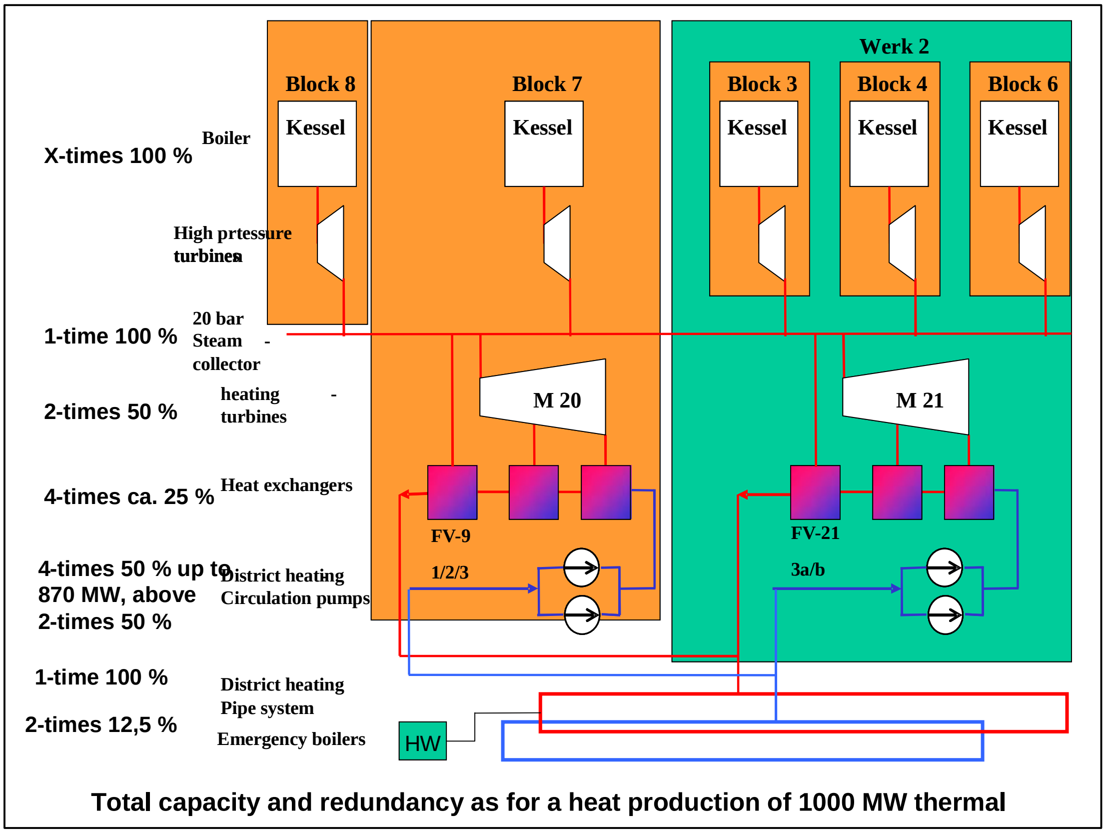


Figure B1. Co-generation of heat and power at Mannheim's large CHP plant

Pumps

There are two pump sets in each supply line. One supply line consists of one CHP steam turbine with two connected water heaters. An additional water heater is heated directly by 20 bar steam in case of peak load demand.

The pump set consists of two booster pumps and two main pumps. A redundant drive is provided by two electric motors that drive a booster pump and a main pump each. The situation of parts in one of the heat supply lines are shown in Figure B2.

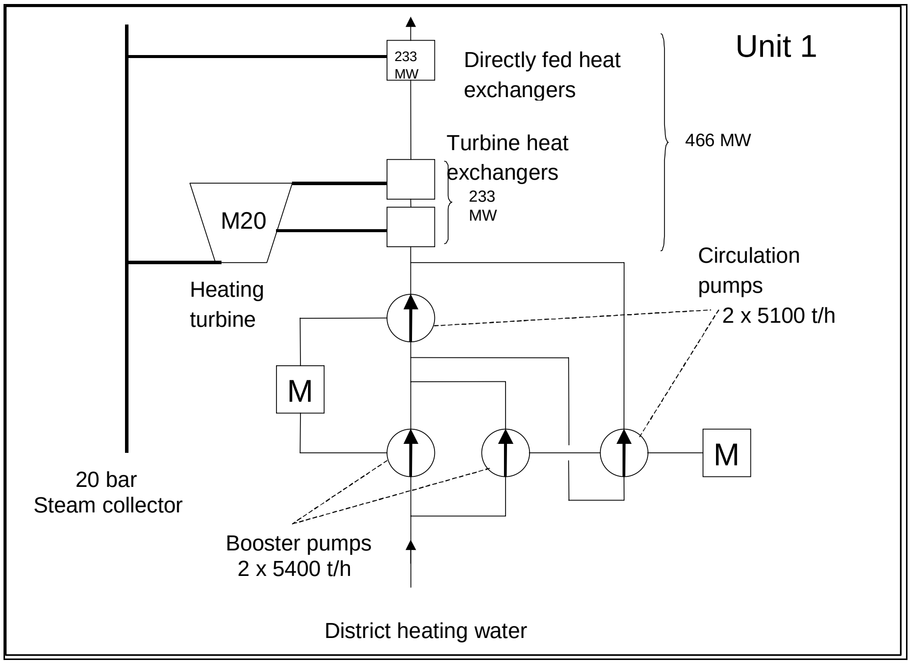


Figure B2. Scheme of the heat supply lines at the GKM

DH Network Connection

The hot water generated at the GKM is being fed into three major pipelines of the district heating network. The diameters of network pipes connected ranks from 600 up to 1,000 mm (Figure B3).

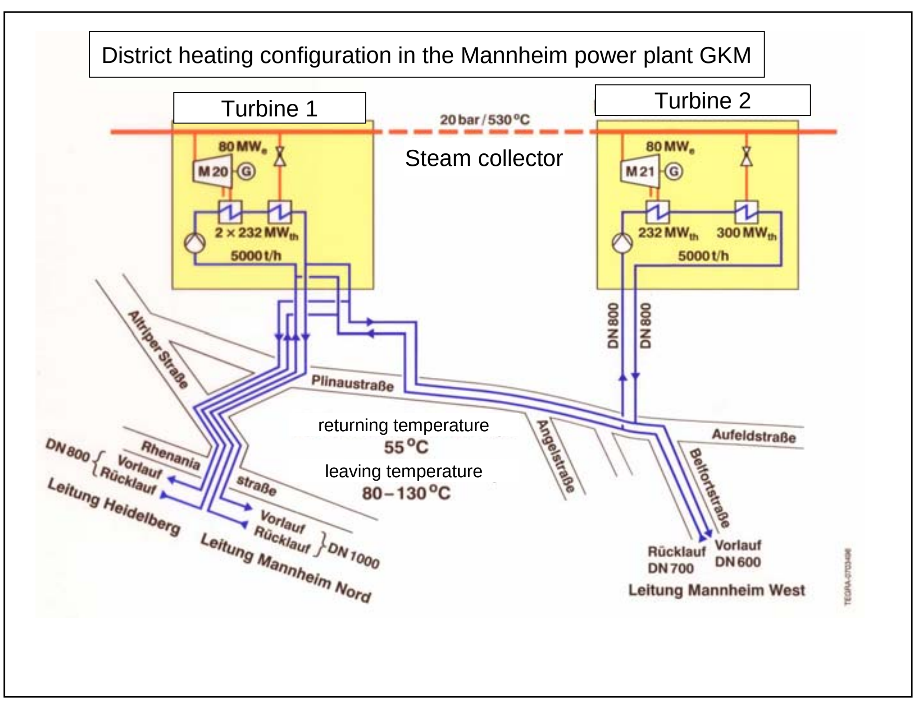


Figure B3. Connection of the two heat supply lines at GKM to the DH network

Heat Distribution System

Pipe Materials and Insulation

The Mannheim district heating network is a meshed dual-pipe high-temperature grid with an overall pipeline length of 516 km and an average diameter of DN 150.

The following laying technologies are applied:

- 423 km polyurethane (PUR) pre-insulated plastic jacket pipelines
- 56 km pipelines above ground level or in the basement of buildings
- 20 km steel jacket pipes
- 10 km hooded channel
- 7 km thermo-concrete covered pipes.

The primarily used pre-insulated pipes have the insulation thickness class 1, which is the smallest standard insulation thickness. The insulation thickness depends on the dimension of the medium pipe. As an example the insulation thickness of pipes with DN 25 is 25 mm and of pipes with DN 600 is 83 mm.

Overhead/basement pipelines and pipes in hooded channels are insulated with mineral wool. The insulation thickness varies from 40 mm up to 100 mm.

The insulation thickness of steel-jacketed pipelines is similar to pipelines in hooded channels. To some extent the space between the steel medium pipe and steel casing pipe is evacuated.

In the thermo-concrete laying system the insulation consists of gas-aerated concrete that is situated around the steel medium pipes.

Manufacturers of Pipe Materials

The following companies are manufactures of pre-insulated plastic jacket pipelines and are accredited at MVV Energie.

isoplus Fernwärmetechnik Vertriebsgsellschaft mbH
Aisinger Straße 12
D-83026 Rosenheim
Tel. +49 (8031) 650-0
Telefax +49 (8031) 650-110
http://www.isoplus.de/english/index.shtml

Lögstör Rör Germany
Werkstrasse 2
D-24955 Harrislee
Telefon +49 (461) 77305-0
Telefax +49 (461) 77305-60
http://www.logstor.com/

BRUGG Rohrsysteme GmbH
Adolf-Oesterfeld-Straße 31
D-31515 Wunstdorf
Telefon +49 (5031)170-0
Telefax +49 (5031) 170-170
E-Mail info@brugg.de.

ALSTOM Power Flow Systems
Ruhrorter Straße 55 A
D-46049 Oberhausen
Telefon +49 (208) 82 446-0
Telefax +49 (208) 82 446-10.

A/S STAR PIPE
Treldevej 177
DK- 7000 Fredericia
Telefon +45 7620 3266
Telefax +45 7620 3268
E- Mail starpipe@starpipe.dk.

Some of these manufactures are also offering steel-jacketed pipes.

Does These Manufactures Serve the U.S. Market?

The European manufactures of pre-insulated plastic jacket pipes serve also the U.S.-market.

Is There an Alternative Piping Manufacturer?

For pre-insulated plastic jacket pipelines the following company could be seen as alternative piping manufacturer.

FinTherm Praha –KWH Pipe a.s.
Za trati 197
Treboradice
Telefon +420 2 66753305
Telefax +420 2 83933015
E-Mail korec@fintherm.cz.

Installed Costs

For assessing the installed costs of the Mannheim district heating network the replacement value was calculated. Thereby it was assumed that:

- Partially old pipelines must be removed.
- New pipelines could be partially installed above the old pipes without removing the old pipes.
- In the case of a new alignment, the pipes will be partially installed one above another.
- If the old alignment will still be used, the pipes will be installed side by side.

Costs/Meter Installed

Today mainly pre-insulated plastic jacket pipelines would be used if district heating networks will be newly installed. The maximum supply temperature of such networks will be below 140 °C. Therefore the following listed costs correspond to the installation of pre-insulated plastic jacket pipes. The mentioned spectrum of costs is characteristic for Germany and might vary in other countries, due to the comparatively high share of construction and other works in total costs. The way how pipes are installed does also differ in different countries.

By using special laying techniques for pre-insulated pipes developed at MVV Energie the installation costs could be clearly reduced.

The installation of DH pipes is comparatively cheap in areas where construction works needed are not complex. This changes significantly as soon as the installation takes place in areas with fortified surface and a number of underground installations already in place (Tables B1 and B2).

Have Any of the Pipes Been Replaced with New Materials?

In the beginning of the 1960's the so-called Thermocrete-System was installed in the Mannheim district heating network. Here the supply and return pipes made of steel are placed in gas-aerated concrete (thermoconcrete). The Termocrete-System was cost-efficient and the construction time was short. At that time MVV Energie's activities were focused at a massive expansion of district heating. After a short useful life of approximately 10 years many of the laid pipelines began to corrode due to cracks in the gas-aerated concrete. Water from the surrounding soil migrated through these cracks and caused outside corrosion of the steel pipes.

Table B1. Specific installation costs of pre-insulated pipes, laid in settlement areas or areas with unfortified surface (source: EWU-catalogue)

Dual-pipe system DN	Specific installation costs [EUR/$m_{\text{pipeline length}}$]
25	175 – 220
32	185 – 225
40	195 – 240
50	210 – 260
65	230 – 280
80	245 – 300
100	270 – 325
125	305 – 375
150	335 – 415
175	370 – 455
200	400 – 490
250	460 – 565
300	540 – 665
350	590 – 730
400	660 – 805
450	705 – 865
500	755 – 925

Table B2. specific installation costs of pre-insulated pipes, laid in city centres, areas with fortified surface or areas with a high density of customers (source: EWU-catalogue)

Dual-pipe system DN	Specific installation costs [EUR/$m_{\text{pipeline length}}$]
25	325 – 395
32	340 – 410
40	360 – 440
50	380 – 465
65	405 – 495
80	440 – 530
100	490 – 600
125	550 – 675
150	630 – 765
175	670 – 820
200	740 – 905
250	860 – 1050
300	990 – 1210
350	1115 – 1365
400	1225 – 1500
450	1300 – 1585
500	1390 – 1700
600	1590 – 1955
700	1790 – 2185
800	1910 - 2355

Until now most pipes of the Thermocrete-System were replaced by pre-insulated plastic jacket pipes, which cause costs comparable to the Thermocrete-System but have a considerably longer service life. MVV Energie is one of the first users of pre-insulated pipes in Germany.

Were There Difficulties Connecting New Systems to Old Ones?

There exist design features for all kinds of changes from one system to another. The necessary effort depends on the respective application. In general the effort will increase if systems with different strains (e.g., pipes in hooded channel and pre-insulated pipes) or with different medium pipe material (e.g., steel and copper, steel and plastics) will be connected.

Pipe Placement: Underground, Hooded Channel, above Ground Level, Other

In principle the laying techniques of district heating pipelines can be divided into three groups. First district heating pipelines could be laid in hooded channels. Further district heating pipelines can also be laid above the ground level. The third group corresponds to earth-laid pipelines.

Today most of the newly installed district heating pipelines are buried in the ground due to economical reasons. Using this laying method the civil engineering costs can be reduced and the construction time will be short. Thereby pre-insulated plastic jacket pipes are mostly applied.

In difference to conventional construction parts of the buried pre-insulated pipelines do not need anchors. The surrounding earth serves as an anchor for the shear stress arising from different temperatures. This circumstance requires sufficient quality of the heat insulation and jacket pipe, of the connection of these compounds to the steel pipe inside and a careful installation.

Laying district heating pipelines in hooded channels causes high installation costs due to high expenses for the civil engineering part. It also requires a lot of areas with no other service pipes or cables. Therefore this laying technique will not be used anymore.

Also laying of district heating pipelines above the ground level could be considered today as special laying technique that is applied very seldom for supplying settlement areas. The disadvantage of this technique is that the pipelines claim areas that cannot be used for other purposes.

In general there are three ways installing district heating pipelines above the ground level. First district heating pipelines can be placed on columns made of concrete. The construction of these columns requires high investments and also enough unused areas. Second district heating pipelines can be installed on a concrete base. In this case the investments are lower but the insulation of the pipes can easily be damaged e.g., by vandalism.

District heating pipelines could also be installed within buildings. For sub-distribution reasons the pipelines can be laid in the basement. In this case there will be no civil engineering costs.

Range of Fluid Flow

Main transmission pipelines:	max. 3.5 m/s
Distribution pipelines:	max. 2.0 m/s
House service connections:	0.5 – 1.0 m/s.

Length of Pipes in the System

The overall pipeline length of the system amounts to 516 km. This means that there are installed 516 km of supply pipes and 516 km of return pipes, in total 1,032 km of pipes.

Temperature Drop from the Central Heating Plant to the Last Customer

Having in mind that 82 percent of the district heating network of Mannheim consist of pre-insulated plastic jacket pipes with an average dimension of DN 150, the temperature drop can be calculated as follows:

The thermal conductivity of the insulation material is specified with 0.027 W/(m*K). Under average operating conditions

- supply pipe 98 °C (208 °F)
- return pipe 59 °C (138 °F)
- soil temperature 10 °C (50 °F)
- velocity of 1.5 m/s.

The temperature loss can be calculated to approximately 0.4 K/km pipeline length. Therefore the temperature drop from the central heating plant to the last customer connected to the network is in the range of 1 – 6 K.

Pipe Expansion System

Considering pre-insulated plastic jacket pipes no expansion joints are necessary. The expansion compensation will be naturally constructed by the pipeline route by using L-shaped and Z-shaped expansion bends.

Pipelines that are laid above ground level or in hooded channels require axial and/or lateral expansion joints. Additionally, L-shaped, U-shaped and Z-shaped expansion bends are used. Also the steel jacket pipeline system requires expansion joints.

Age of Piping System

The oldest district heating pipes installed in Mannheim were constructed in 1959 using the hooded channel laying technology.

The first pre-insulated plastic jacket pipes were installed in 1968. MVV Energie was the first company using this innovative pipeline system.

The average age of the district heating network pipes in Mannheim is 20 years.

Annual Maintenance Activities

The annual maintenance activities correspond to:
- detection of leakages
- replacement of pipe sections
- replacement of fittings within the network and substations
- replacement of heat meters
- repair of inspection chambers.

Expansion Joint Problems

Expansion joints within a pipeline system could be generally considered as a weak point in the network. They are expensive components that have limited load alternations. The installation of expansion joints requires additional construction costs due to necessary inspection of chambers and anchor points. Expansion points could also be susceptible to stress corrosion cracking.

Piping Leakage History

Some 82 percent of the total pipeline length of the Mannheim district heating network consist of pre-insulated plastic jacket pipes. Some 95 percent of these pipes have a leak detection system within the insulation of the pipes.

The remaining pipeline length is monitored regarding to leakages by using infrared thermal imaging or by periodically checking inspection chambers. This procedure ensures that leakages can be detected in a very early state and the necessary re-investments can be kept at a low level. The annual specific rate of leakages of the whole network is very low and amounts to 0.06 leakages per 100 km pipeline length.

Statistical data at MVV Energie shows that most of the leakages occur during the first 2 years of operation. So it is possible to regulate the necessary expenses for repair within the period of guarantee that covers normally a 5-year period.

Pipe Repair Methods

In case of necessary repair the following techniques could be used.

Draining the Pipeline

Conventionally laid pipelines with up-points and low-points can completely be drained very easily. But this technique requires a lot of operational staff and the heat supply of the respective area is interrupted. In case that larger pipe sections have to be repaired the supply needs to be retained by using provisionally laid pipes.

Pipe Freezing

Pipe freezing is a simple process to plug water filled pipes. It uses the solidifying of water when cooled below its freezing point. The ice plug forms a local stoppage that is tight against high pressure. The pipe blockage can be removed by simply melting the ice. Although this process works simply it requires very special know-how to apply it correctly as well as particular care in its usage.

For pipe freezing a cooling collar filled with a cooling agent is wrapped around the water-carrying pipe. The cooling agent could be alcohol, liquid gas (Nitrogen), CO_2-dry-ice or brine.

Pipe freezing (Figure B4) is economical reasonable for pipe diameters up to DN 100.

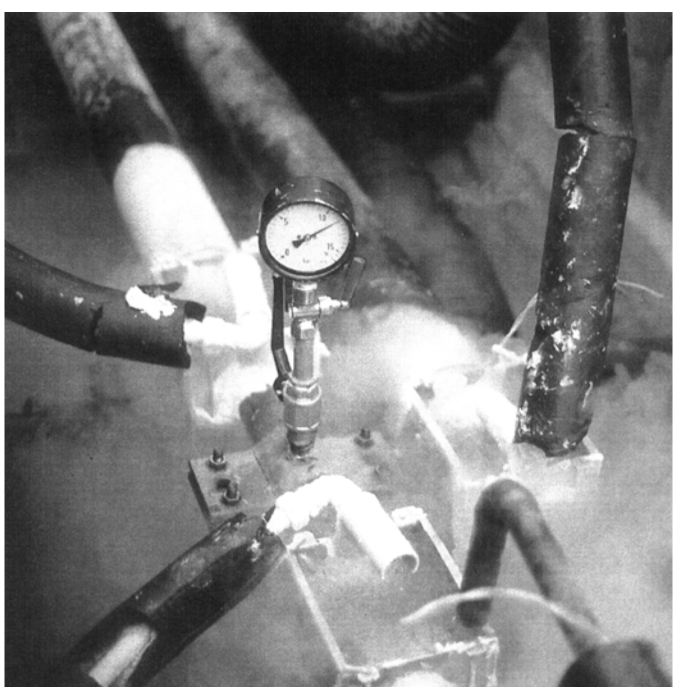


Figure B4. Pipe freezing of a district heating pipeline with liquid gas, MVV Energie.

Simple Barriers

When the pipeline lies flat in the underground it often takes a long time to completely empty a separated section and the time required can hardly be estimated. Small quantities of water often flow hours after draining and hinder the progress of repairs, as welding cannot be undertaken when water is flowing. Usually it is sufficient to hold back the water flow in front of the weld for a short time. For this purpose, damming disks can be used for example. There are also pipe plugs that can keep the pipeline closed under pressure (Figure B5).

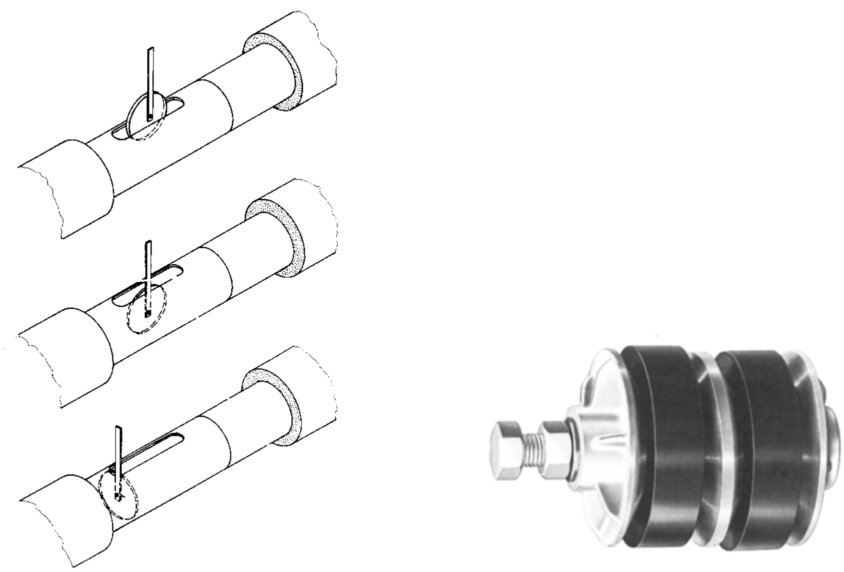


Figure B5. Damming disks and pipe locking plug.

Provisional Repairs

Leaks in district heating pipelines occur more often during high loads in cold weather. During these times interruptions to the supply are particularly unwelcome. If conditions allow a provisional repair will first be carried out and the damage will be completely removed later at a more favourable point in time.

For a provisional sealing of leaks in smooth pipeline components repair clamps have proved themselves in many instances (Figures B6 and B7). A repair clamp is a collar that is fixed with screws around the pipe. A soft seal is fitted inside the collar, so that the leak is sealed. The final repair can be postponed for several months up to a maximum of 1 year using repair clamps.

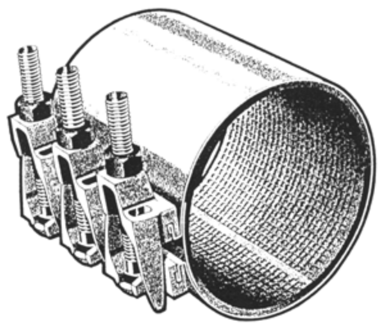


Figure B6. Repair sleeve.

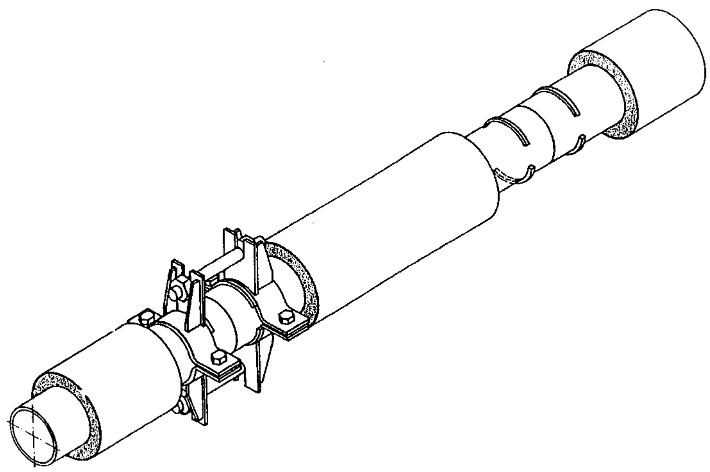


Figure B7. Retaining clip for pre-insulated pipes.

Pre-Insulated Plastic Jacket Pipes under Axial Stress

According to the laying process and operating temperature, district heating pipelines can be under high axial stress. When the pipeline is separated or if the pipeline cross-section is noticeably weakened, for instance by a large tapping, then the stress condition must be taken into account. If necessary static calculations must be undertaken.

Spot Boring

This method is generally applied at MVV Energie to connect customers to an existing district heating network during operation without any interruption of the supply.

Frequency of Component Replacement

Considering pre-insulated plastic jacket pipes maintenance-free fittings are used. Today mostly ball valves are applied. These fittings are con-

nected to the pipes without flanges, they are welded to the pipes. Therefore no sealings have to be changed after a certain time. For pipes smaller in diameter than DN 200 there are no fittings installed for draining and exhausting the pipeline.

Pipe sections or fittings will only be replaced if there are leakages. The philosophy of maintenance could be considered as an event-driven strategy. Using that strategy it is very important to detect leakages in a very first state by applying leak detection methods at certain time intervals.

Protection from Freezing

During normal operation of the district heating system there is a mass flow of hot water with a certain velocity inside the pipes and there is no danger that pipes will freeze. Only in special pipe sections freezing could occur. These are pipe sections at the end of distribution pipelines or building service connections that are out of service. Here the mass flow tends to be zero. In these cases a small bypass between supply and return pipe can be installed provisionally, together with a pressure reducer to prevent these pipes from freezing.

Using pre-insulated plastic jacket pipes the standard insulation thickness could be increased in artic conditions. In Germany insulation series 1 is the standard insulation thickness applied. Pre-insulated pipes are also offered in insulation series 2 and 3. The insulation thickness of series 2 is approximately 40 percent higher than that of series 1 and the insulation thickness of series 3 is approximately 80 percent higher than series 1.

If Pipes Are Laid Directly in the Underground, How Can They Protected from Corrosion?

Today the most commonly used laying system buried in the soil are pre-insulated plastic jacket pipes. The steel medium pipes are covered with a polyurethane insulation and a polyethylene casing pipe. The casing pipe and also the pipe connections are water tight.

Steel jacket pipes are protected from corrosion by using cathodic corrosion protection systems for the steel casing pipes. If pre-insulated pipes will be connected to steel jacket pipes an insulation component has to be installed between these two systems.

Is There Continuous Flow through All Pipes?

The district heating system of Mannheim is a very intermeshed network that improves the security of supply in the connected areas. Dependent on the temperature and pressure conditions there could be pipe sections were the mass flow could be very low. At the end of the distribution pipes and in house service connections that are out of order but still connected to the grid the mass flow can be zero.

Building Interface Specific to Benjamin Franklin Village/U.S. Army Garrison

Building Type

Military barracks (housing).

Size

129 Substations are connected to one metering station with a total of 23 MW_{th} (78.5 MBTU/h) or 162 m^3/h supply.

Distance from Heating Plant

The distance to the GKM CHP is approximately 12 km.

Entering Fluid Temperature

The supply temperature ranges from 85 – 130 °C (185 °F ... 266 °F) depending on the outdoor conditions.

Leaving Fluid Temperature

The return temperature is at the level of approximately 50 °C (122 °F).

Function/Process with Hottest Temperature Demand/Req'd Temperature

The heat is only used for radiator space heating, air heating and domestic hot water preparation. The required maximum temperature of the heating system at the winter peak is around 90 °C (194 °F).

Other Heating Energy Users

There are no other heating users supplied by district heat.

Heat Exchanger Types

In the substations soldered plate heat exchangers from various manufacturers are used.

Any Reboilers Including Detailed Description

There are no reboilers installed.

Problems with Heat Exchangers

There are no problem reported.

Is the Temperature Adjusted by Season

The temperature is automatically adjusted according to the outdoor temperature as measured by a sensor.

Is Temperature Adjusted by Daily Demand

No. The temperature in the DH network is depending on outdoor temperature.

Summertime Heat Exchanger Effectiveness

All heat exchangers have to be able to cover the winter peak demand with maximum network temperature (operating parameters primary side in/out: 266 °F/122 °F, secondary side in/out 117 °F/194 °F). The summer load is mostly used for domestic hot water preparation (operating parameters primary side in/out: 185 °F/140 °F, secondary side in/out app.: 131 °F/158 °F). Heat exchangers are specified accordingly.

Type of Controls

In case of the Benjamin Franklin Village, the customer uses an electronic control system from the manufacturer Kieback & Peter, Berlin. The control system is operated by the customer. All control valves possess motor drives. There is no pneumatic system installed.

What Is Sensed/Measured

Mainly the secondary side outflow temperature, the primary side return flow temperature and the outdoor temperature.

How Is Leaving Temperature Varied

The maximum allowed temperature of the fluid leaving the substation at the primary side is limited. When it exceeds the allowed temperature the controller set point switches from the secondary side outflow temperature according to the heat curve to the primary side return flow temperature.

Problems with Controls

No problems reported.

Annual Maintenance Activities

Inspections are regularly performed each 30 months at most indirect substations and each 20 months at direct substations.

Cost of Annual Maintenance

See district heating Issues Part D (costs are approximately $170 per year and substation).

Frequency of Component Replacement / If Low Temperature System with No Heat Exchanger

Since the pressure level at the district heating network is higher (16 bar) than in the buildings (typically 6 bar) pressure reduction valves and safety release valves are installed that need frequent checks and are therefore more expensive to operate.

Do Hot Water Consumers Have Any Cost Incentive That Would Affect Their Use?

MVV Energie has one contract with the U.S. Army. The bill is based on the heat measured at the central heat metering station for all 129 substations together. We do not know how the Army assigns heat amounts and respective bill to the various consumers. As far as we know there are no additional heat meters installed.

How Are Consumers Billed? / Gallons Used / Energy Consumed

The MVV Energie tariff for annual billing consists of a:

- “capacity charge,”
- an “energy charge,” and
- a “meter charge.”

The capacity charge depends on the maximum district heating water flow through the customer installation. This flow is limited by a sealed control valve. As the district heating network is a water transport system the water flow is the parameter that is limited by the capacity of the system.

The energy charge depends on the consumed heat as measured by a heat meter in kWh (energy charge). The meter charge is a lump sum fee, which depends on the size of the heat meter.

Additionally, there are access charges that are charged only once when the customer is connected to the network. These access charges depend on the size of the DH substation and the length and diameter of the connecting pipes to be installed. As it was stated above in case of the Benjamin Franklin Village, this tariff is applied only to the central point of delivery. All buildings at the territory used by the U.S. Army are supplied from this central point of delivery.

District Heating Issues, Part A: Best Piping Material and Location of District Heating Pipes

Are There Better Materials than Steel Pipes Enclosed in Steel?

Today pre-insulated plastic jacket pipes are widely applied. Pre-insulated pipes consist of a steel pipe that is covered with an insulation made of polyurethane-foam and a casing pipe of polyethylene. The pipes are buried in the ground.

Pre-insulated pipes are available with three standard insulation thicknesses. In the Mannheim district heating network only pre-insulated pipes with the lowest insulation thickness (Series 1) are used. Pre-insulated pipes are applicable for network supply temperatures up to 130 °C (266 °F) and must withstand temperatures of 140 °C for a maximum of 500 h/a. They are suitable for pressures up to 40 bar (Mannheim district heating network operates at max. 16 bar) and are offered on the market in a spectrum from DN 20 up to DN 1000.

Pre-insulated pipes are a very cost-effective laying technique that needs little space in the road. The system could be adapted to the pipeline route without any expansion joints and short construction times are feasible.

The expected useful life of pre-insulated pipes is specified with more than 30 years. Investigations done in Mannheim on 30 years old pre-insulated

pipes showed that the total useful life could be assumed with 70 years provided the network is accordingly operated and maintained.

New Piping Components and Their Limitations

For supplying areas with hot water with a system pressure < 5 bar and long term operating temperatures up to max. 80 °C (176 °F), peak temperatures < 90 °C [194 °F] earth-laid pipelines with a pre-insulated plastic medium pipe can be used. The plastic medium pipe is covered with an insulation made of polyurethane-foam and a casing pipe of polyethylene.

In district heating networks the system is used for medium pipe dimensions with an outer diameter of 110 mm (this corresponds to steel pipes DN 80).

Due to the plastic medium pipe and the friction-locked connection of the insulation and the casing pipe, the pipe expansion can be considered as very low. Therefore no special pipe expansion measures are necessary.

The systems today available on the market are characterized by a very small diffusion of water vapour from the hot water through the plastic medium pipe into the insulation material. Therefore the thermal conductivity of the insulation material increases during lifetime. In consequence the heat losses of such pipes will increase during lifetime.

What Temperature Loss Is Experienced ?

The thermal conductivity of the insulation material is specified by manufacturers with 0.030 W/mK. In ordinary operating conditions (supply pipe 80 °C, return pipe 40 °C (104 °F), soil temperature 8 °C [46 °F]) the temperature loss can be calculated for a 75 mm pre-insulated plastic medium pipe to approximately 0.002 K/m pipeline length.

Investigate Piping Material Suitability for Continuously Warm and Saturated Ground Conditions Such as the SE United States

Pre-insulated plastic jacket pipes are generally applicable for warm and saturated ground conditions. In that case PE-welded sleeves have to be used due to their water resistance.

Additional Information to the District Heating Network Supplying the Area of Benjamin Franklin Village In Mannheim

History

Before the area of Benjamin Franklin Village was connected to the district heating network there were coal fired boilers installed for heating up buildings and water for domestic use. In the majority of the cases every single building was supplied with one coal fired gas boiler. Due to the installation of a district heating network it was possible to prevent CO_2-emissions in that area. At the same time the security of supply of the buildings with heat could be increased.

Temperature Drop per 1.000 Meters of Pipe – What Is the Heat Loss Experienced with the Sites to Be Visited?

Operating Temperature of System Supply and Return Pipe

The district heating network supplying the area of Benjamin Franklin Village is directly connected to the district heating grid of Mannheim. Therefore the operation mode (supply temperature) could be characterized as variable dependent on the ambient air temperature. The maximum supply temperature is 130 °C (266 °F), the return temperature varies between 50 °C (122 °F) and 60 °C (140 °F) during the year.

Piping System Length/Pipe Materials

The area of Benjamin Franklin Village is supplied with district heat by pipelines with approximately 5,300 m pipeline length in total. Here pre-insulated plastic jacket pipes are used.

Pipe Sizes and Thickness Insulation

The pipe dimensions cover a spectrum of DN 25 up to DN 250 with an average nominal diameter of DN 100. Insulation series 1 (thinnest standard insulation thickness) represents the standard case.

Type of Distribution — Underground, Aboveground or in Trenches

All pipes are directly buried in the soil.

The Placement of the Distribution System

Pre-insulated plastic jacket pipes are used. These pipes are directly buried into the ground.

The soil in Mannheim is very sandy and problems with ground water do rarely appear. Therefore the connecting sleeves of the used pre-insulated pipes are completed by ordinary shrink sleeves.

In the case of constant ground water PE-welded sleeves have to be used due to their water resistance.

During normal operation there is a mass flow of water with a certain velocity inside the pipes and no danger that pipes will freeze. Only in special pipe sections freezing could occur. These are pipe sections at the end of distribution pipelines or house service connections that are out of service. Here the mass flow tends to be zero. In these cases a small bypass between supply and return pipe can be installed provisionally, together with a pressure reducer to prevent these pipes from freezing.

Using pre-insulated plastic jacket pipes the standard insulation thickness could be increased in artic conditions. In Germany insulation series 1 is the standard insulation thickness. Pre-insulated pipes are also offered in insulation series 2 and 3. The insulation thickness of series 2 is 40 percent higher than that of series 1 and the insulation thickness of series 3 is approximately 80 percent higher than series 1.

Ability to Connect New Pipe Systems to Existing Piping Systems

Connecting new pipes to pre-insulated pipes are generally possible at all times. Thereby the static conditions of the distribution pipe (strain and expansion) have to be considered. At MVV Energie the method of spot boring is applied to connect new customers to the network. Thereby no interruption of the supply of other customers will occur that could be seen as the big advantage of that method.

District Heating Issues Part B: How Effective Are Variable Temperature Heating Systems?

Figure B8 (heating water supply temperature) shows the guaranteed values of supplied water to the customers depending on the outside temperature of the Mannheim district heating system.

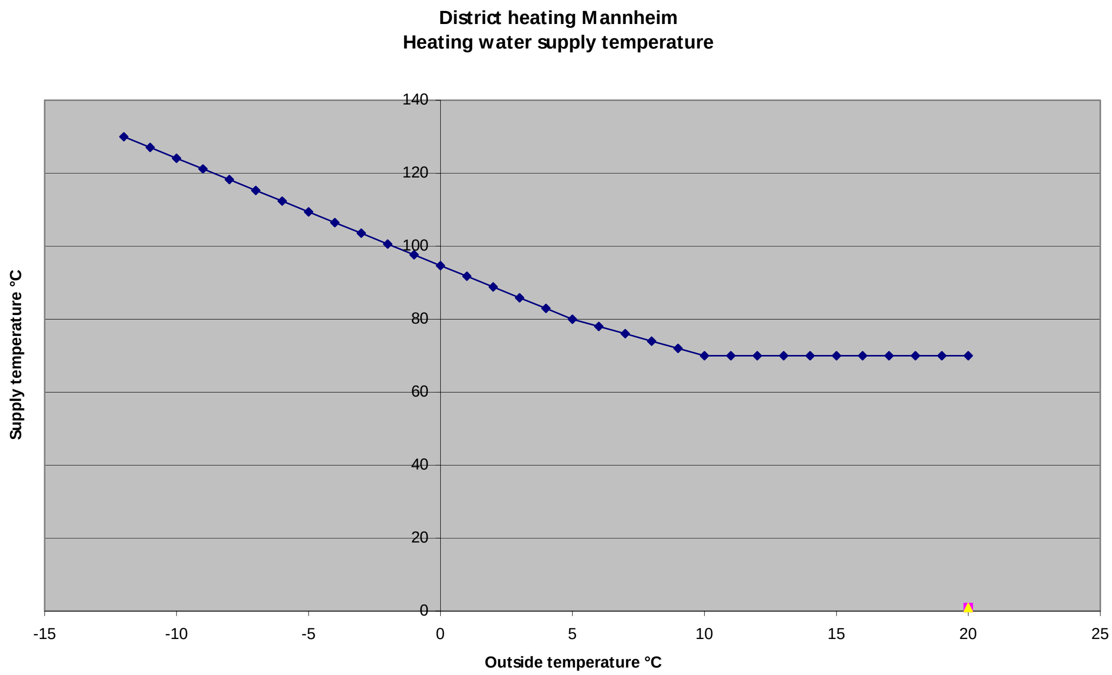


Figure B8. Supply temperature of the DH network versus outside temperature.

District Heating Issues, Part C: What Can Improve the Efficiency of the Central Heating Plants?

The efficiency can generally be improved by:

- the use of cogeneration
- operation with supply temperatures as low as possible.

This means that:

- The supply water temperature from the heating plant should be as low as possible (depending on the characteristics of the heating system fed by this water). [and]
- The temperature of the return flow should be as low as possible as well (i.e., 50 to 55 °C [122 - 131 °F]) or lower.

The steam turbine from which the heating steam is withdrawn should allow for the extraction of the low-grade heat amount during the summer months with a good rate of efficiency. This means that the turbine (or a particular "summer turbine") must be able to work close to its best point in spite of small steam flows. Part loads of the turbine that reduce the efficiency should be avoided.

How Effective Is Cogeneration?

Cogeneration reduces the primary energy input by some 40 percent compared to a separate production of the same amount of heat and electricity.

This advantage can also be quantified by the coefficient of use of the heat input into a cogeneration plant. The heat is used up to 80 to 85 percent.

Is Electricity Generated in the Central Heating Plants? If So How Do They Operate the Generation with A Varying Hot Water Demand?

There is a simultaneous generation of heat and electricity in Mannheim.

The heat energy supplied to the city linearly depends on the product of water flow rate and the difference of temperature between supply and return flows.

For hydraulic reasons a certain pump pressure must be assured. By this measure a certain water flow is reached. Depending on the outside temperature this water flow is warmed up maintaining a constant pressure in the supply line to the city. If the users need more heat energy their control systems admit more water in their heating installation that would reduce the pressure in the supply line. This is compensated by an increase of water flow trying not to increase the temperature (see above). For reasons of hydraulic stability, the maximum flow at each customer is restricted by a respective device.

The design of the steam turbines allows for a heat supply of about 600 MW_{th} (2,050 MBTU/h) by reaching the highest water flow and a supply water temperature of 100 °C (212 °F).

Larger heat demands are satisfied by increasing the water temperature up to 130 °C (266 °F) keeping the maximum water flow. This supplementary heating is realized by using direct steam condensing heaters (20 bar steam), which are installed downstream of the heaters connected to the turbine.

Is Steam Generated and Converted to Hot Water or Is Hot Water Heated Directly in Hot Water Generators/Boilers

Steam is used for heating up the district heating water. This is related to the fact that first the Mannheim power plant is an electricity plant and the heat supply is an additional business.

There is no direct water heating. The water is heated up with steam having already provided most of its exergy to electricity production in the steam turbine.

The energy requirement for heat production is measured by the loss of electricity generation i.e., the cogeneration plant's power production is compared to the same parameter at a condensing power station. This coefficient is about 175 kWh_{el}/MWh_{th}.

Which Heat Recovery Systems Are in Use and How Much Energy Do They Save?

There are no heat recovery systems installed. The only use of recovered heat is the integration of the residual heat of the condensed water of the water heaters in the preheating system of turbine condensate of the power plant. This is not a special heat recovery system of the district heating system but a normal element of a power plant.

Are Variable Speed Pumps Installed in the Distribution System ?

Yes.

What Are the Turn-down Ratios of the HW Generators?

As there is a permanent heat demand of at least 100 $MW_{thermal}$ in the city throughout the year. The turbine heat exchangers of at least one operating turbine are active all the time, even at a very low load rate. There is no minimum load required for the heat exchangers.

How Were the Generators Sized for the Installation (N + 1)?

At the GKM CHP plant there are four units for heat generation installed. Each of them covers some 25 percent of the system's peak heating load.

In addition there are two emergency heat generators (peak heating plants) with a total capacity of some 250 MW_{th} (853 MBTU/h) capacity available

at two different points in the city. This capacity also makes up 25 percent of the peak heating load in the system.

Accordingly if one of the units at the CHP plant should fail there would still 100 percent of peak heating supply capacity available. The n+1 criterion is therefore fulfilled.

District Heating Issues, Part D: What End Use Options Exist That Accomplish Energy Savings?

Does Varying Hot Water Temperature Throughout the Day Work ?

Yes, it works. Hot water temperature for space heating via radiators should vary in accordance with outdoor temperature. Typical hot water temperatures for space heating by radiators are within the range of 50 °C to 90 °C (122 °F...194 °F). Design and installation of the building's heating system is behind the "point of delivery" of MVV Energie's district heating supply and therefore the customer's job. As an additional business we offer to the customer so called "compact substations," which mainly consist of:

- the heat exchanger to separate the building's heating system from the District Heating Network,
- the valve to control the building's heating system by opening and closing the heating water that enters the heat exchanger from the network,
- electronic control devices incl. hot water sensors and outdoor sensor,
- the heating water pump,
- the expansion tank,
- eventually domestic hot water preparation tank and additional heat loop control devices.

The customer is not obliged to use compact substations from MVV Energie. He is free to choose a contractor or may build a substation on his own, install a compact substation from MVV Energie, or install the substation of another manufacturer.

Typically each radiator is equipped with a thermostatic valve. Air conditioning systems are equipped with customized control systems. A typical design that is applied to smaller and medium size customers is presented below. Today we install almost exclusively substations of the indirect type (i.e., a heat exchanger separates the building's heating network from the district heating network). Direct substations are still in use in elder systems or in case of large industrial customers where the heating system is easily accessible and well-maintained (Figure B9).

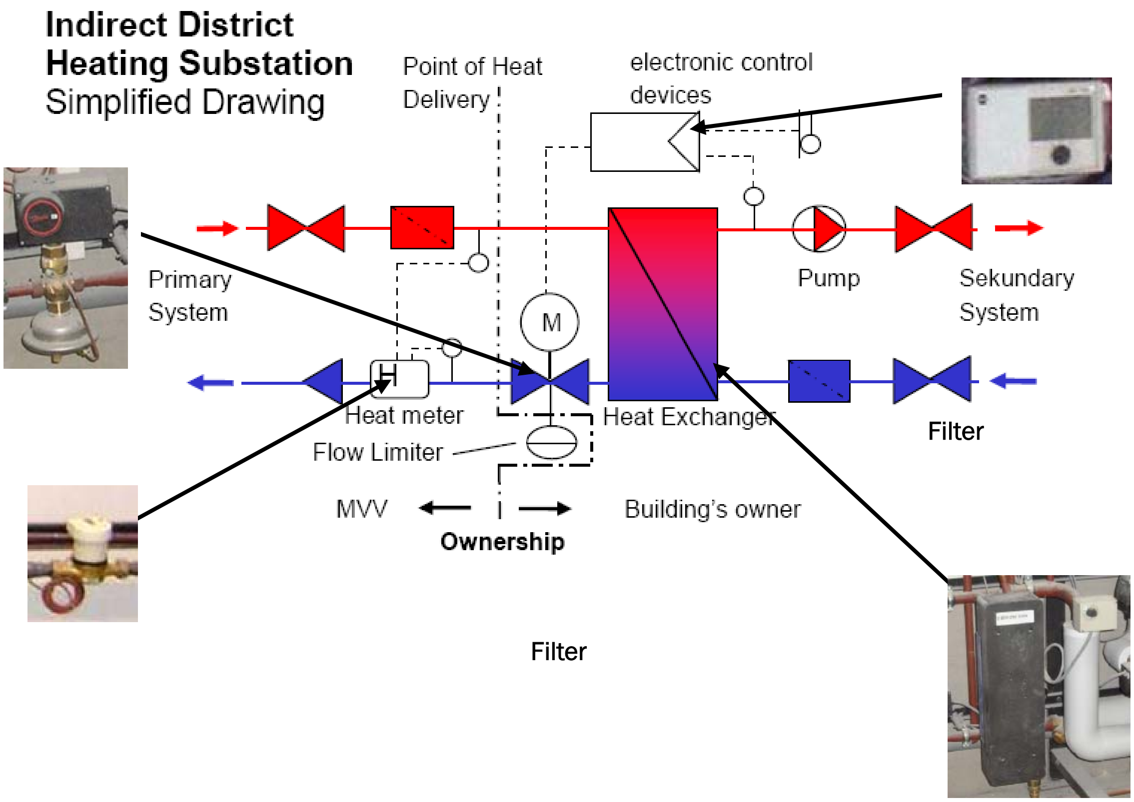


Figure B9. Typical indirect heating substation (building heating only).

Are There Billing Practices That Provide Heating Savings?

Billing is mainly based on the quantity of heat measured by the heat meter (consumption charge) and the maximum district heating water flow possible (capacity charge). The latter is limited by a sealed second drive at the control valve.

Length of Time for Temperature Adjustment To Be Experienced by Users Some Distance Away

The network's supply temperature is adjusted according to outdoor conditions between 85 °C and 130 °C (185 °F... 266 °F). We do not consider the time delay between power plant and customer (up to 5 hours and more during summertime with low flow rates) to be of high relevance. Weather conditions typically change slowly and also heating systems possess slow system dynamics.

As part of the substation there is a second heat medium temperature control loop in place. This second control loop controls the hot water temperature at the building level. The customer is free to adjust the heat curve (=relationship between outdoor temperature and heating water tempera-

ture set point) at the substation's electronic control device that is in his ownership. The temperature at the district heating network therefore only determines the maximum possible level of the heat medium temperature at the customer side.

Do the Users of the Hot Water Have Any Incentives to Consume Hot Water at Different Times of the Day? How Do They Pay for the Hot Water Used?

Customers do not have incentives to consume hot water at different times of the day. The equipment necessary to heat up tap hot water is part of the heating central and in the ownership of the customer. The heat energy needed for water heating is recorded at the heat meter as part of total heat consumption. The cold water to be warmed up is measured by the water meter, which in the case of the city of Mannheim, is delivered by the same company (MVV Energie based on a separate contract).

9.3 District Heating Issues, Part E: What is done to reduce maintenance costs ?

Is There Stand-by Equipment Available ?

Yes, the important devices within our ownership (mainly filter, energy meter, the sealed maximum flow limiter, pressure control valves, safety valves etc.) are stocked.

Additionally, we have the main components of those compact substations supplied by us in stock. Maintenance contracts and 24 hour per day emergency services are offered as an additional service to customers against separate charge.

Are Preventative Maintenance Practices Used?

We routinely inspect indirect substations every 30 months and direct substations every 20 months. Together with a routine inspection we replace the heat meter after every 60-month period since their approval expires. Direct substations (=connection of the building to the network without heat exchanger, until today around 2/3 of the total) have to be inspected more often since certain devices used at direct substations like pressure reduction valve, differential pressure valve, safety release valve etc. are critical for a safe operation.

Constant Temperature Change Affect on Expansion Joints – Concern Here Is Extra Maintenance and Quicker Failure.

We typically do not use expansion joints. Pipes are installed by using suspensions that are able to oscillate. We typically suspend pipes at the ceiling by using threaded rods with pipe clips. The rods compensate thermal expansion. Equipment should be installed at fixed points to avoid tensions at flanges or threaded fittings.

What Is the past Experience of Operations and Maintenance Costs?

Our average operation and maintenance costs are around 170 €/a per year for small and medium sized indirect substations up to some 1 MW (3.4 MBTU/h). Since the secondary side is operated by the customer this figure does only refer to the part of the substation that is in the ownership of MVV Energie. Around 50 percent of the total are maintenance and repair costs, 30 percent to cover call services and technical information of customers, the rest (approximately 20 percent) are administrative and overhead costs. Time needed for traveling to the substations causes a major part of maintenance costs and may be different in other locations.

What Is the Staff of the Plant?

Substations are not staffed. They are controlled by electronic control devices.

Frequency of Component Replacements (Piping, Valves, Etc.)

Every 20 months we replace pressure control valves and safety release valves that are installed in direct substations. These devices are checked at our workshop and re-installed in the field. Checking on site would be more expensive.

All the other devices are only replaced when necessary.

Water Chemistry To Reduce Fouling, Etc.

There are no organic substances in the district heating network. Also there is no light, so we have no problems with fouling. Regarding the water chemistry we maintain and ensure the following properties:

ph-value: around 9.5.

Release of magnetite from steel pipes cannot be avoided. Since, at a ph-value of 9.5 the capability of water to dissolve magnetite is at its optimum, we add soda lye to the district heating water. The magnetite can then be extracted by mechanical filters at the GKM power plant. Magnetite that is not dissolved appears as mood in the pipes and may congest control valves or heat exchangers.

- Conductivity: <30 microsiemens/cm
- Hardness < 1 mg CaOH/l
- We keep salt and CaOH/l content at a low level to avoid sedimentation.
- Oxygen <20 microgramm/l

We keep the oxygen content at a low level to inhibit inside corrosion.

Annex 1: Refurbishment of Kiel's DH steam system

General Information

In the year 1905 the district heating supply by a steam network started in Kiel. The hot water network is continuously developed since the early 1960s and it continuously takes over the supply function of the old steam network.

Today more than 60,000 apartments, as well as many public buildings, including department stores, administrative and commercial buildings as well as the university and hospitals are connected to the district heating network.

The spread of district heating was also pushed forward by the construction of additional power stations: between 1967 and 1975 the heating turbines in Wik*, the joint venture power generating plant on Kiel's east bank and the city's waste incineration plant joined the network's supply.

A further big step in achieving area-wide supply occurred in 1996. Following the conversion of Kiel's waste incineration plant into a modern waste-fueled combined heat and power plant it was also able to supply district heating into the network of Kiel's public utility company.

At present Kiel is supplied with heat from a total of six heat and/or power stations (Table B3).

* Wik is a district of Kiel.

Table B3. Heat sources of Kiel's district heating steam network.

No.	Name	Function	Total capacity
1	Heating plant North	Peak and reserve plant	180 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)
2	Heat and power plant Humboldtstrasse	Second power plant in Kiel	28 MW_{el}; 176 MW_{th} at 130 °C / 80 °C (266 °F/ 176 °F)
3	Heating plant West	Peak and reserve plant -	41.8 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)
4	Waste Incineration plant (Heating plant South)	—	~60 MW_{th}
5	Joint venture power generating plant	Joint venture of E.ON (national-wide energy supplier) and Kiel department of works	320 MW_{el} (largest power plant in Kiel, 50% electr. for E.ON, 50% for Kiel dep. of works), 295 MW_{th} at 130 °C / 80 °C (266 °F/ 176 °F)
6	Heating plant East	Peak and reserve plant	60 MW_{th} at 130 °C / 80 °C (266 °F / 176 °F)

The largest of these plants, the joint venture power generating plant on Kiel's east bank, produces more than 60 percent of heat energy for the district heating system.

With the conversion of district heating from steam to hot water in the inner city area Kiel's public utility works has been preparing itself since 2002 for the future. Over the next few years, the company intends to invest more than 30 million Euro to make its district heating network even more cost-effective and to carry out state-of-the-art upgrades.

From 2001 to 2005, the share in customers supplied with district heating from steam dropped from about 35 percent to less than 25 percent.

District Heating System Name

The considered district heating system is called the Kiel district heating system (steam network, under refurbishment) (Figure B10).

Situation

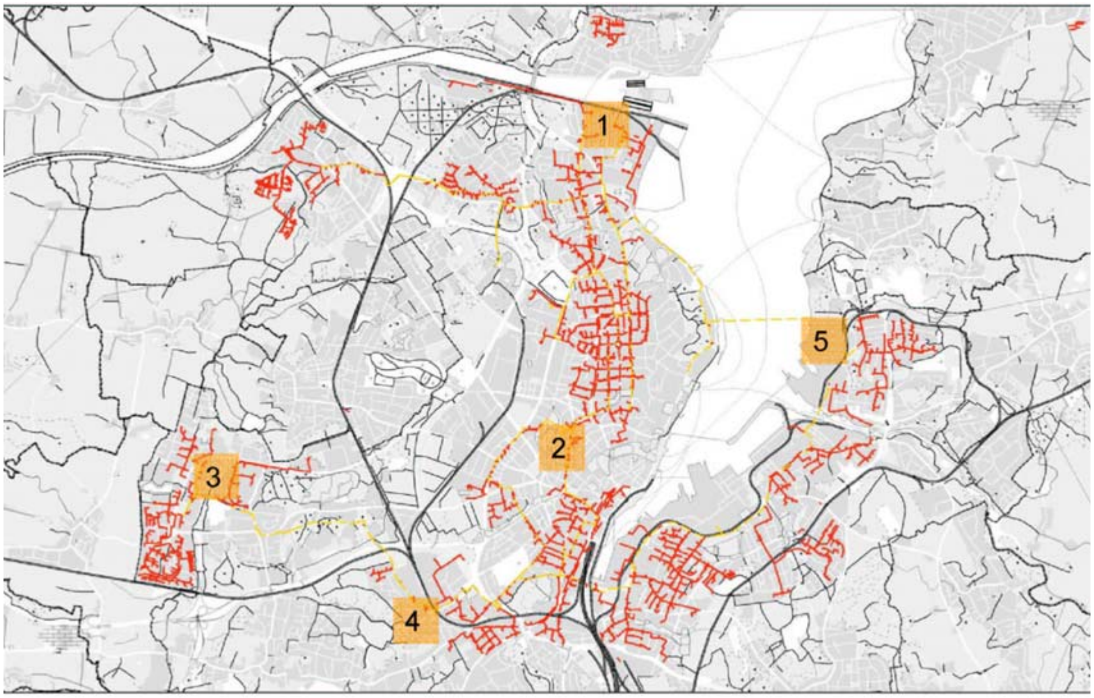


Figure B10. The hot water network in Kiel. Figures correspond to the numbers of the plants in the table in the "General information" given above.

The hot water networks today represent the large share of district heating networks. Figure B11 shows the steam networks still in operation.

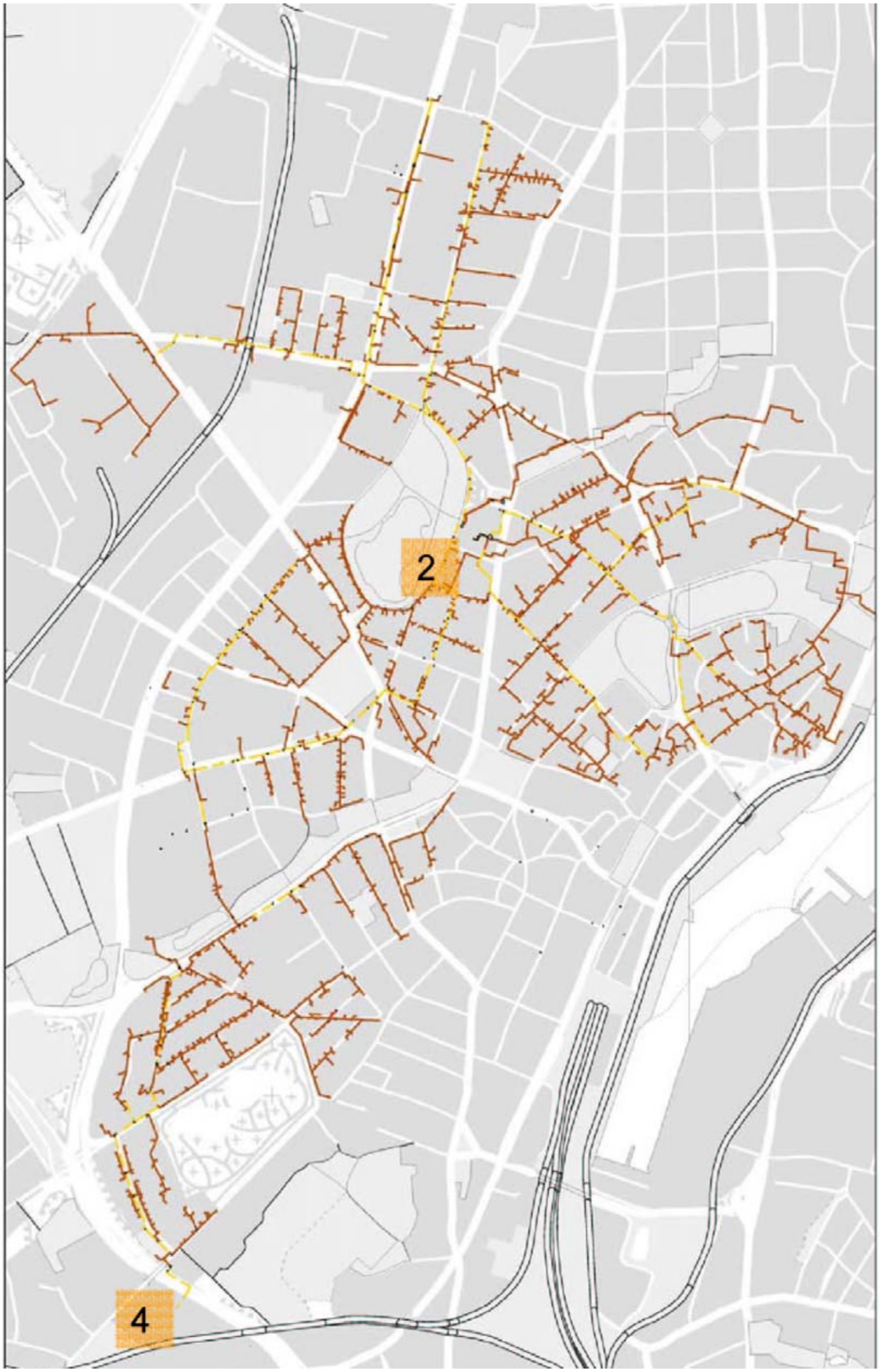


Figure B11. The steam network in Kiel. The figures correspond to the numbers of the plants in the table in the "General information" given above. Maps have different scales.

In the following text all information is related to the Kiel steam network exclusively if not indicated otherwise.

Type of Buildings Served

The spectrum of supplied buildings includes multi-family houses and public buildings.

The total connected load in the Kiel steam network is 278 MW_{th} (950 MBTU/h) of which:

- 162 MW_{th} (553 MBTU/h) are for the 1,571 connections for apartment buildings, and
- 116 MW_{th} (396 MBTU/h) are for the industry and public buildings. The great majority of this connected load is for public buildings.

Number of Buildings and Total Area Served

1,571 customers are connected to the district heating system.

Supply and Return Temperatures:

The supply temperature is 160 °C (320 °F) on the average and varies between 150 °C and 180 °C (302 °F and 356 °F).

The return temperature is about 55 °C (131 °F).

In summer of 2006, the last customer for the second steam pressure level (i.e., the hospital at the university) will switch to hot water supply. Then this pressure level (10.5 bar at 190 °C: 374 °F) will be switched off.

Central Heating System

Number and Size of Boilers

The Kiel steam district heating system is based on two heat stations (176 MW_{th} and 60 MW_{th} resp. 601 and 205 MBTU/h). The smaller one is used for waste incineration. The four other plants serve the hot water network, (Table B4).

Type of Fuel(s)

The fuels used in the power plant are natural gas, fuel oil, and solid waste.

Table B4. Heat generators for district heating in Kiel.

No.	Name	Fuel	Supply of the...
1	Heating plant North	Natural gas and heating oil	...hot water network directly
2	Heat and power plant Humboldtstrasse	Natural gas and heating oil	...steam network and hot water network
3	Heating plant Mettendorf	Natural gas	...hot water network directly
4	Waste Incineration plant (Heating plant South)	Municipal and solid waste	...steam network and hot water network
5	Joint venture power generating plant	Hard coal	...hot water network
6	Heating plant East	Natural gas and heating oil	...hot water network directly

Maximum Load

The maximum thermal load is 100 MW_{th} (120 tons/h of vapour or 341 MBTU/h). However, the steam generators can supply the hot water network if necessary.

Annual Energy Consumption

The annual consumption of heat from the steam network is about 260 GWh/a (887,153 MBTU/a) plus an unknown amount from the waste incineration (Figure B12).

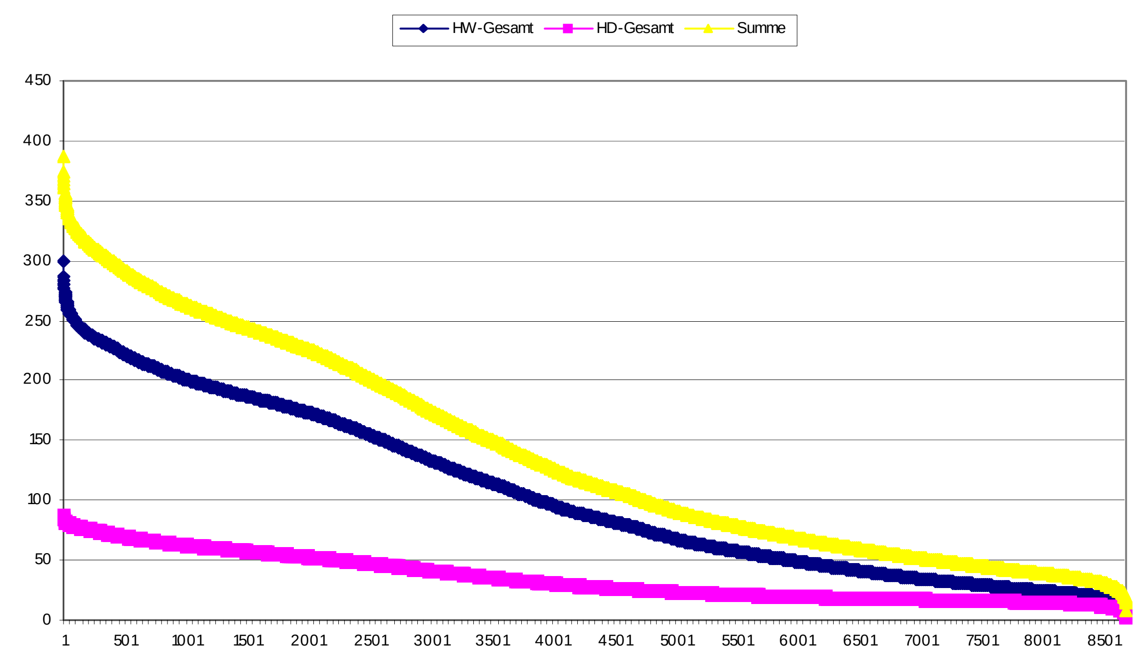


Figure B12. Annual energy consumption for steam (lower line), hot water (medium line) and on the total.

Generated Fluid

The heat transport fuel is steam.

Pressure and Temperature

The maximum pressure is 2.5 bar and 180 °C (356 °F). The steam is overheated by 40 K.

The thermal insulation of the pipes is made of mineral fibres, the compensation of extensions by elbows and compensators. Both technologies are applied in the same amount.

Number of Employees

On 30 September 2005, the Kiel department of works had in total 1,286 employees for the sectors gas supply, electricity supply, water supply and district heating. For district heating (steam and hot water) the core staff comprehends 80 employees. For special or additional works more service staff can be employed.

Have Steam Driven Turbine/Generators

- two back pressure turbines (38 bar, steam: 1 - 2.5 bar) for the district heat system plus two gas turbines
- one back pressure turbine (38 bar, steam: 1 - 2.5 bar) in the waste incineration plant.

Pumps

For the return of the condensate pumps are installed in each house station and another three in the network (Table B5).

Distribution System

Table B5. Condensate pipes installed in the DH steam network of Kiel (length in meters).

Condensate	GUS	MR	WK	Sum
25	510.33	105.74	9,319.44	9,935.51
40	2,255.69	239.59	8,185.24	10,680.52
50	2,267.22	287.27	11,823.69	14,378.18
65	1,277.04	626.12	5,207.78	7,110.94
80	560.74	119.20	4,958.45	5,638.39
100	571.54	368.21	4,099.33	5,039.08

Condensate	GUS	MR	WK	Sum
125			195.81	195.81
150	63.65	578.33	5,586.88	6,228.86
200			1,780.94	1,780.94
250			263.37	263.37
300		43.92	426.17	470.09
350		9.31	270.69	280.00
400		520.52		520.52
500		30.74	1,061.87	1,092.61
600			64.84	64.84
Sum	7,506.21	2,928.95	5,3244.50	63,679.66
MR: Jacket pipes, WK: Hooded channel, GUS: Solid surrounding (gravel etc.)				

Figure B13 shows an overview of installed condensate return pipes. Figure B14 gives an overview of installed steam supply piping.

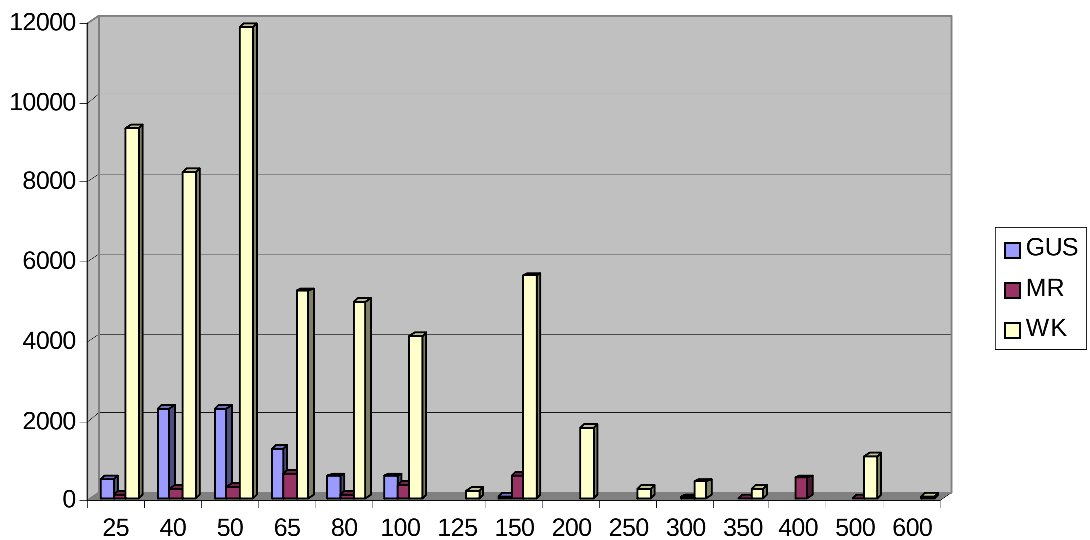


Figure B13. Overview of condensate return piping systems installed. Left side = length of pipes in meters, bottom = diameter in mm.
MR: Jacket pipes, WK: Hooded channel, GUS: Solid surrounding (gravel etc.).

Table B6 lists the steam supply pipes currently installed.

Table B6. Steam supply pipes installed in the DH steam network of Kiel (length in meters).

Vapour pipes	GUS	MR	WK	Sum
25		105.74	53.31	159.05
40	0	239.59	172.98	412.57
50	239.16	287.27	5,008.33	5,534.76
65	1,151.24	626.12	5,221.14	6,998.50
80	1,076.29	119.20	7,615.26	8,810.75
100	1,601.69	376.22	8,357.08	10,334.99
125	102.48		195.81	298.29
150	1,478.28	578.33	7,310.38	9,366.99
200	474.49		5,872.37	6,346.86
250	639.35		2,771.02	3,410.37
300	265.17	35.91	3,333.26	3,634.34
350	478.06	9.31	1,149.17	1,636.54
400		520.52	3,085.52	3,606.04
450			1.80	1.80
500		30.74	2,474.17	2,504.91
600			622.90	622.90
Sum	7,506.21	2,928.95	53,244.50	63,679.66

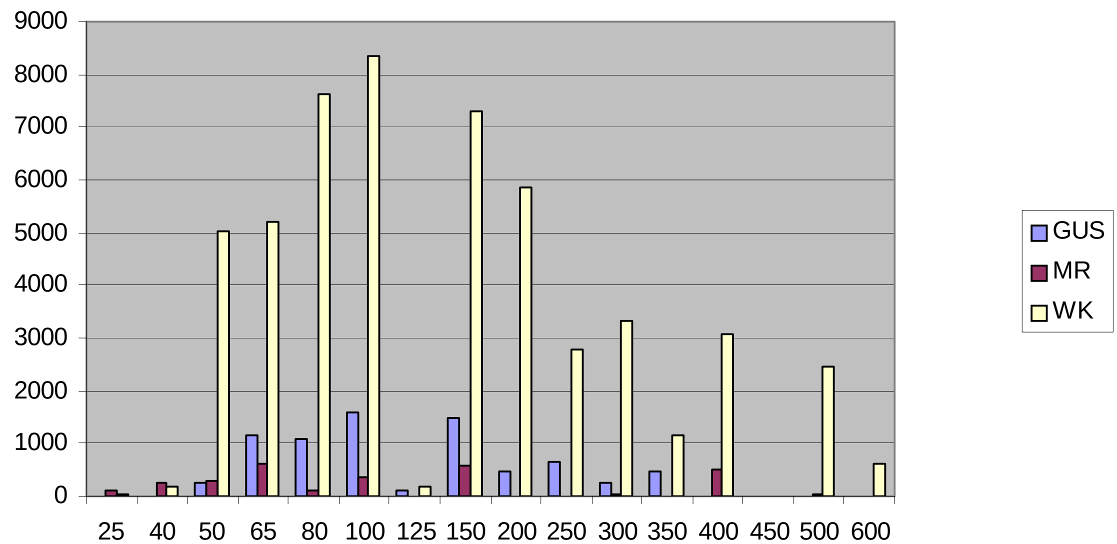


Figure B14. Overview of steam supply piping systems installed. Left side = length of pipes in meters, bottom = diameter in mm.

MR: Jacket pipes, WK: Hooded channel, GUS: Solid surrounding (gravel etc.)

Pipe Materials and Insulation

Steel, sound proofing, gas-aerated concrete.

Manufactures of Pipe Materials

FWT Wärmetechnik AG, Isobrugg.

Does These Manufactures Serve the U.S. Market?

Most likely.

Is There an Alternative Piping Manufacturer?

In Germany the standards and norms are set by äAGFW (Association of district heating suppliers). Every manufacturer can supply parts and materials if the respective requirements are fulfilled.

Installed Costs

There are no current data as (since years) the steam network is reduced and switched to the hot water network.

Costs/Meter Installed

See above.

Have Any of the Pies Been Replaced with New Materials? / If So, What Type?

Yes, by steel jacket pipe (Figure B15).

Figure B15. Steel coated pipes for vapour and condensate in Kiel (various photos).

Figure B15. (Continued).

Figure B15. (Cont'd).

Were There Difficulties Connecting New Systems to Old Ones?

No, as all works have been carried according to AGFW requirements (especially n °FW 410 and FW 436).

Pipe Placement: Underground, Hooded Channel, above Ground Level, Other

The pipes are installed in hooded channels.

Range of Fluid Flow

The range of fluid flow is between 0 and 70 m/s.

Length of Pipes in the System

In Kiel, there are currently 63,679.66 m of pipeline alignment, see tables above.

Temperature Drop from the Central Heating Plant to the Last Customer

The temperature drop from the central heating plant to the last customer is up to 40 °C (40 K). It happens all year long, the are no seasonal changes.

In the steam network a temperature at the building substation of 160 °C (320 °F) must be guaranteed, even if a single customer requires only small amounts of energy. In the hot water network, 70 °C (158 °F) must be maintained. The energy saving from this difference is one of the reasons for switching the steam supply to the hot water system.

Pipe Expansion System

Compensators, expansion bends.

Age of Piping System

5 to 60 years depending on the section.

Annual Maintenance Activities

Only minimum maintenance activities as the steam supply is switched continuously and completely to the hot water system.

Costs of Annual Maintenance

The annual costs for maintenance amount to less than 0.5 Mio. EUR/a.

Expansion Joint Problems

Possible, but rare in practice.

Piping Leakage History

Table B7 lists leak history data for the Kiel pipeline systems.

Table B7. Leak history in the pipeline systems in Kiel.

Parameter	Year						
	1998	1999	2000	2001	2002	2003	2004
Steam network							
High pressure	17	10	8	11	9	13	10
Low pressure	0	0	0	0	0	0	0
Number of leakages	17	10	8	11	9	13	10
Hot water							
Mettenhof	2	0	6	1	7	3	5
North/South	26	8	17	22	16	20	21
East	10	6	0	4	3	1	2
Island network	1	0	0	0	0	1	1
Number of leakages	39	14	23	27	26	25	29
Total	56	24	31	38	35	38	39

Pipe Repair Methods

Repair is done only at small leakages in the steam network. Wherever possible and appropriate the steam network is changed to a hot water system.

Frequency of Component Replacement

See above.

Protection from Freezing:

The network is run all the year at the same temperature. Freezing protection is therefore not needed.

If Pipes Are Laid Directly in the Underground, How Can They Protected from Corrosion?

Condensate pipes are coated with PE (polyethylene).

Is There Continuous Flow through All Pipes

Yes.

Building Interface

There are no more plants using the steam directly, all clients are served via steam / hot water heat exchangers.

Building Type Serviced

Multi-family houses, public buildings.

Size

70 to 100 kW_{th} for multi family houses up to 2.3 MW_{th} for the hospital.

Distance from Heating Plant

Max 4 km alignment.

Entering Fluid Temperature

160 °C (320 °F).

Leaving Fluid Temperature

app. 55 °C (131 °F).

Function/Process with Hottest Temperature Demand

Hospital at the University.

Required Temperature

190 °C (374 °F), 10 bar.

Other Heating Energy Users

Please refer to "building type."

Heat Exchanger Types

Miscellaneous. A number of special customer-tailored types.

Any Reboilers

No reboilers installed.

Problems with Heat Exchangers:

Yes, by contamination from the customer side, e.g., from open reservoirs or from corrosion at customer side over summer if only heating is supplied.

Temperature Adjustment during Season

Please refer to the answer to "Temperature drop from central heating plant to the last customer."

Is Temperature Adjusted by Daily Demand

Please refer to the answer to "Temperature drop from central heating plant to the last customer."

Summertime Heat Exchanger Effectiveness

> 95 percent.

Type of Controls

Mainly control of condensate return flow by switch contacts and change of used exchanger surface to keep the temperature constant on the customer side.

What Is Sensed/Measured

The flow rate of the condensate is sensed, and varies strongly depending on:

- the parameters of the heat exchangers
- the current load.

How Is Leaving Temperature Varied

+ / - 10 Kelvin.

Problems with Controls

No problems reported.

Annual Maintenance Activities

Unknown, as they are carried out by the customers.

Cost of Annual Maintenance

Unknown, as the maintenance is to be carried out by the customers.

Frequency of Component Replacement

5 to 20 years.

If Low Temperature System with No Heat Exchanger, Any Problems

None, as this is a steam system.

Do Hot Water Consumers Have Any Cost Incentive That Would Affect Their Use?

Yes, as tariffs consist of a capacity charge and a kilowatt hour rate (Table B8 lists the consumption charge, with values in Euros).

Table B8. Tariffs applied to steam customers.

Step	2	3	4	5	6	7	8	9	10	11	12	13	14
Consumption exceeding x t/a	44	57	74	97	128	168	221	290	382	503	661	869	1,142-1,513
Base price	82.15	106.80	139.66	183.48	240.98	317.65	416.24	547.68	720.21	947.50	1,245.98	1,637.58	2,152.4
Kilowatt hour rate cents: 19.93													

District Heating Issues, Part A: What Is the Best Piping Material and Location of District Heating Pipes?

Underground installation is preferable. Hooded channels or steel jacket pipes are an equally suitable solution.

What Is the Temperature Range for Those Materials?/ Are These Piping Systems Placed Underground?

Pipes in hooded channels can be used up to 240 °C (464 °F), also for underground placement.

What Temperature Loss Is Experienced?

Precise data for new materials are not available. For data in practice please refer to the answer to “Temp. drop from central heating plant to last customer.”

Investigate Piping Material Suitability for Continuously Warm and Saturated Ground Conditions Such as the SE United States

These pipe materials are certified and can be used in hot and wet underground (steel jacket pipes).

Temperature Drop per 1.000 Meters of Pipe – What Is the Heat Loss Experienced with the Sites to Be Visited?

Operating Temperature of System Supply and Return Pipe

See above.

Piping System Length/Pipe Materials

See above.

Pipe Sizes and Thickness Insulation

Condensate pipes are not insulated.

New pipes are insulated with PE for protection against humidity. Additionally, they have an insulation of rockwool (e.g., 5 to 6 cm for pipes of 80 – 100 mm, 10 cm for pipes of 300 – 400 mm diameter).

Type of Distribution – Underground, above Ground or in Trenches

Trenches.

Installation Capital Costs: Total and Then Averaged to A Unit of Length (Meter) Value.

No current data available as the steam system is under deconstruction.

The Placement of the Distribution System – Are the Pipes in the Ground, Trenches or Somewhere Else? What Is Done To Protect against Ground Water and Freezing (for Arctic Conditions)?

Protection against corrosion by a coat of steel, protection against freezing by insulation. However, the hot medium will not freeze under conditions given normally in Kiel.

Ability To Connect New Pipe Systems to Existing Piping Systems

No as all works have been carried out according to AGFW requirements (especially n °FW 410 and FW 436). For details please refer to the part "distribution system."

District Heating Issues Part B: How Effective Are Variable Temperature Heating Systems?

There is no intended variation of the temperature heating systems in the Kiel steam district heating system.

2.7 District Heating Issues, Part C. What Can Improve the Efficiency of the Central Heating Plants?

How Effective Is Cogeneration?

Back pressure turbines are operated in the heat and power plant Humboldtstrasse and in the waste incineration plant. In the heat and power plant Humboldtstrasse the temperature varies between 150 and 180 °C

(302 °F and 356 °F), the waste incineration plant produces a constant temperature of 150 °C (302 °F).

Efficiency of the cogeneration is >85 percent.

What Heat Recovery Systems Work Best?

There is no heat recovery system in the Kiel steam network.

Is Electricity Generated in the Central Heating Plants

The power generation runs based on heat demand in general. Surplus heat energy is transferred to the other district heating networks.

Is Steam Generated and Converted to Hot Water or Is Hot Water Heated Directly in Hot Water Generators/Boilers. What Is the Thermal Efficiency of the Hot Water Generation?

Please refer to the information in the part "Central heating system," "types of fuel."

What Heat Recovery Systems Are in Use and How Much Energy Do They Save?

There is no heat recovery system in the Kiel steam network.

Is the Distribution Systems Variable Flow Using Variable Speed Pumps?

Yes, but only in the hot water system.

What Are the Turn-down Ratios of the HW Generators?

From April to October, the system works in the "summer modus": the high pressure steam turbines are switched off, the gas turbines and the turbines in the waste incineration plant are working. The gas turbines are controlled by a load management system. Based on the weather forecast the load management system produces a load forecast, which is the basis for the management and control.

How Were the Generators Sized for the Installation (N + 1)?

Yes, by the (N+1) method.

District Heating Issues, Part D: What End Use Options Exist That Accomplish Energy Savings?

Does Varying Hot Water Temperature Throughout the Day Work?

The heating installation at customer side are operated according to outdoor temperature.

Are There Billing Practices That Provide Heating Savings?

Please see above (customer billing).

Length of Time for Temperature Adjustment To Be Experienced by Users Some Distance Away

In the steam network the is no temperature change. After leakages, a period of 20 to 30 min could be measured until effects from the heating plant reach the most remote building. In the hot water network the respective time is about 6 to 8 h.

Do the Users of the Hot Water Have Any Incentives To Consume Hot Water at Different Times of the Day

No.

What Is Done To Reduce Maintenance Costs?

The change from the steam system to the hot water system.

Are Stand by Equipment Available?

No stand by equipment for the steam system, only little for the hot water system.

Are Preventative Maintenance Practices Used?

No, as in the current period, all financial means available are needed for the switch of the steam system to a hot water system. Therefore no strategic renewal is currently possible.

Constant Temperature Change Affect on Expansion Joints – Concern Here Is Extra Maintenance and Quicker Failure.

There are no temperature change in the steam network.

In the hot water network, no dramatic temperature changes are observed, therefore, no extra maintenance costs are expected.

What Is the past Experience of Operations and Maintenance Costs?

The annual costs for maintenance are less than 0.5 Mio Euro/a. Please observe that the steam network is under deconstruction. (see above).

What Is the Staff of the Plant?

At the Sept. 30, 2005, the Kiel department of works had in total 1,286 employees for the sectors gas supply, electricity supply, water supply and district heating. For district heating (steam and hot water), a core staff comprehends 80 employees. For special or additional works, additional service staff can be employed.

Frequency of Component Replacements (Piping, Valves, etc.)

See above.

Is a Preventative Maintenance Program in Place?

No, as in the current period, all financial means available are needed for the switch of the steam system into the hot water system. Therefore, no strategic renewal is currently possible.

Explain the Water Chemistry, To Reduce Fouling, etc.?

In the steam network, fully desalinated water from the own desalination plant is used. to avoid corrosion the pH value of the water is tuned with ammoniac and sodium hydroxide solution. Nevertheless, corrosion problems arise from contamination at the customer side (see above).

In the hot water network a corrosion protection named “dipolique 504” is added to the fully desalinated water. Corrosion problems only happen by effects from the outside of the pipes (damage etc.).

Appendix C: EcoNet Summary Report

By

Satu Paiho & Jenni Jahn VTT

02 February 2006

Contents

Executive Summary

District heating is the most common heating form in Finland. District heating is produced at CHP plants or at heating plants. Clients receive heat through the hot water, which circulates in the district heating network. The temperature of district heating water varies between 65 and 115 °C, depending on the weather. The pressure difference between the supply and return pipelines makes the district heat flow in the district heat network and in the client's district heat substation. In Finland, the delivery reliability of district heating is almost 100 percent. The total length of the district heat network in Finland is about 9.700 km.

Clients receive the district heat in an industrially manufactured substation, which includes the heat exchangers for heating and service water and, possibly, a heat exchanger for air conditioning, control devices, pumps, expansion and safety equipment, thermometers and manometers, and shut-off valves. In Finland, there are recommendations how heat exchangers and other equipment should be connected in a substation.

The heat used in a building is metered and the heating energy is paid in proportion to the meter reading. The purchase costs of district heating are determined by the contracted capacity. The costs consist usually of a fixed connection fee. The energy fee is composed of a fixed annual demand charge, which depends on the connection capacity, and of an energy unit rate, which depends on the consumed amount of heat. About 30 percent of the district heating costs consist of taxes, in Finland.

District heating is one possible energy source of an ECONET module. ECONET is a packaged liquid-coupled heat recovery system with a unique optimizing control system. It is a part of a building's air treatment system that can also partly or totally take care of space heating and/or cooling. ECONET can also be used in combination with other building energy systems such as radiator heating, floor heating or ceiling cooling.

The ECONET system is using the heat recovery coil in the supply air section of the air handling unit also for normal heating respectively cooling. The ECONET system requires fewer components such as heating/cooling coils, pumps, valves, piping, insulation etc. It results also in a shorter and more compact air handling unit. Additionally, the heat recovery efficiency using ECONET is improved by approximately 15–20 percent compared to traditional run around coil systems. Other benefits of ECONET include:

profitable temperature ranges, numerous possible energy sources, frost protection, low energy costs, and fast amortisation of the investment.

ECONET system can be applied to a variety of building types including hospitals, swimming halls, offices, industrial buildings, residential high-rise buildings etc. Generally speaking ECONET is suited for almost all kinds of applications where heat recovery is possible. Between the years 2000 and 2005, there has been 50 ECONET installations in supermarkets, 300 in offices, 200 in hospitals, and 100 in residential buildings.

ECONET can be connected to many energy sources including district heating, district/local cooling, free and waste energies, distributed CHP (Combined Heat and Power), solar energy, ground water, a boiler, a heat pump, condensation heat, and electric storage heating.

Impacts of ECONET are case and application sensitive. In a comparison between an ECONET system and a traditional liquid heat recovery system, 73 percent heating energy savings and 21 percent cooling energy savings were achieved with the ECONET system. By applying ECONET technology in a supermarket, the consumption of purchased energy may be cut by more than one half when compared to conventional solutions, and electrical consumption may be reduced to one third. In a supermarket in Sweden, the measurements show that nearly 100 percent of the heating energy demand of the air handling and heating of the sales space, was covered with condensing heat from the food refrigeration machines.

The ECONET system reduces the district heat return temperature and total flow especially during peak heat demands. In simulations the district heat return temperature of the ECONET system during peak heat demands was 20 °C lower in the office building and 15 °C lower in the multistory residential building than the return temperature of the reference systems. In the office building the district heat flow of the ECONET system was 30 to 50 percent lower, and in the multistory building 20 to 40 percent lower, than the flow of the reference systems. In the office building the ECONET system used 12 to 34 percent less heating energy, and in the multistory residential building 9 to 29 percent less, than the reference systems.

When comparing existing ventilation and air-conditioning units to the possibility to replace them with ECONET units in an existing hotel building, it was noticed that the heating energy for the ECONET units is cov-

ered by heat recovery and CHP excess heat. In addition, the cooling energy consumption is reduced by 61 percent and the electrical energy for the fans is reduced by 58 percent, correspondingly.

1 Introduction

The objectives of this work were to provide design and cost information regarding district heating systems in Finland and the application of Thermonet/ECONET systems to them and to prepare a portion of a report that describes Finland's district heating and Thermonet/ECONET systems, and discuss their application to U.S. Army installations.

This summary report provides design, performance and cost information of Thermonet/ECONET systems and typical applications in different building types that could be used in U.S. Army installations in the United States. The Finland district heating system and the integration of Thermonet/ECONET systems are also discussed. This summary report is organized as follows: Chapter 2 introduces the main issues of district heating in Finland. Chapter 3, discusses the ECONET technology that can be connected to district heating. Chapter 4 describes ECONET system concepts for heating and cooling of different buildings. Chapter 5 addresses integrated ECONET system solutions. Chapter 6 gives case examples of installations.

2 District Heating in Finland

2.1 General

District heating is the most common heating form in Finland. Almost a half of the Finns (2.4 million) live in district heated buildings. The market share of district heating is about 50 percent in Finland (http://www.energia.fi/). In 2004, the average price of district heating was 3.89 Euro-cents per kWh (http://www.energia.fi/).

District heating is produced at CHP plants or at heating plants (Ala-Juusela 2004). If heat is generated by renewable energy sources (e.g., waste) district heating helps to conserve energy and is environmentally friendly. This conservation is best realized in combined heat and power

(CHP). Useable heat from industrial production can also be used for district heating.

The share of DH produced in CHP plants is 76 percent in Finland, which makes Finland a globally leading country in CHP (http://www.energia.fi/). Finland is often regarded as a country with functional systems with big CHP plants connected to DH networks. Yet small CHP plants (less than 20 MWe) make up 18 percent of the produced heat (IEA District Heating and Cooling 2005).

2.2 Distribution

Clients receive heat through the hot water, which circulates in the district heating network. The temperature of district heating water varies between 65 and 115 °C, depending on the weather. The temperature is at its lowest in summer, when heat is only needed for hot service water. The temperature of water returning from clients to the production plants ranges between 40 and 60 °C (http://www.energia.fi/). In buildings, heat is used for heating spaces, for providing Domestic Hot Water and for air conditioning.

District heating pipelines are installed into the ground typically at the depth of 0.5 – 1 meters (http://www.energia.fi/). The pipelines are thermally insulated efficiently. The heat losses in pipelines are typically below 10 percent. The pressure difference between the supply and return pipelines makes the district heat flow in the district heat network and in the client's district heat substation. The pressure and the pressure difference in the district heating network vary all the time. In winter they are usually higher than in summer. At its highest the pressure in the supply network may be about 1.5 MPa (15 bar). to ensure the proper operation of district heating equipment in normal operating conditions, the heat producer guarantees the pressure difference of at least 60 kPa (0.6 bar) to the client.

The delivery reliability of district heating is almost 100 percent. The district heat networks are most often looped (http://www.energia.fi/) so clients may receive heat from different delivery directions. The district heat client is without heat during 1 hour per year on average due to damages in the district heat networks and operational shutdowns during repair work.

The total length of the district heat network in Finland is about 9.700 km. Pipe sizes vary between a building's service line of 20 mm to a production plant's supply pipe of 1000 mm. In cities and other bigger urban areas the

networks cover almost all the areas that are economically profitable to be connected to the district heating. The annual growth of the network is 200 to 300 km mainly including infilling and new building in the current network. In buildings district heat pipelines, heat producer's shut-off valves, a mud trap, and a heat energy meter belong to the heat producer (Figure C1).

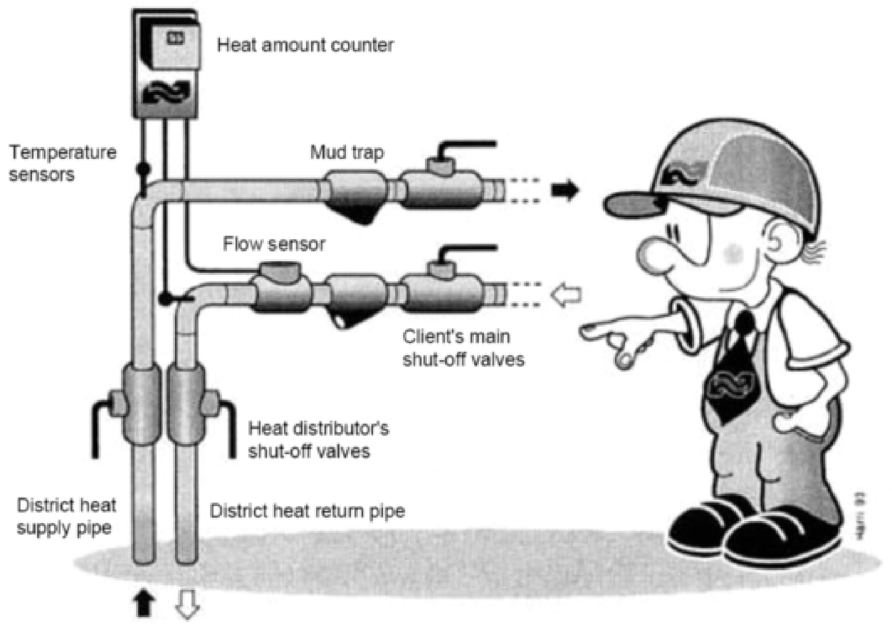


Figure C1. District heat equipment (http://www.energia.fi/) in a building owned by the heat producer.

2.3 Building Systems

Clients receive the district heat in a substation (Figure C2), which includes the heat exchangers for heating and service water and, possibly, a heat exchanger for air conditioning, control devices, pumps, expansion and safety equipment, thermometers and manometers, and shutoff valves (Ala-Juusela 2004). Substations are industrially manufactured units.

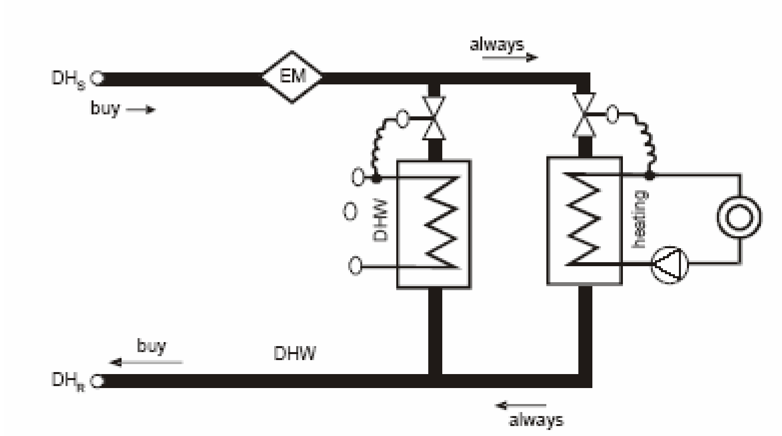


Figure C2. Typical district heating substation in Finland.

District heating water heats the water that flows in general through the heat exchangers, which is then used for the building's space heating system and for hot service water. Temperatures inside the building are kept correct and steady by means of control devices. A control valve regulates the volume of district heating water flowing through the heat exchanger according to the outside temperature. Thus, the temperature of water in the space heating network is regulated automatically. The control curve chosen at the control centre is specific for each building. Thermostatic valves make the regulation of temperature for each room more efficient.

District heating can be used with radiator heating, floor heating, and air heating. In floor heating systems, the operating temperatures can be considerably lower than in radiator networks. It is also recommended to dimension the radiator networks with temperatures as low as possible even though it means larger radiators and higher investments in the building.

2.3.1 Connection Recommendations

In Finland, there are recommendations on how heat exchangers and other equipment should be connected in a substation (Finnish District Heating Association 2003). Figure C3 shows an example of recommended connections of client's equipment. In Sweden, there even exists a recommendation to connect ECONET systems to district heating or cooling (Fjärrvärmeföreningen 1997). Figure C4 shows example connections when heat from exhaust air and low temperatures are used with an ECONET system.

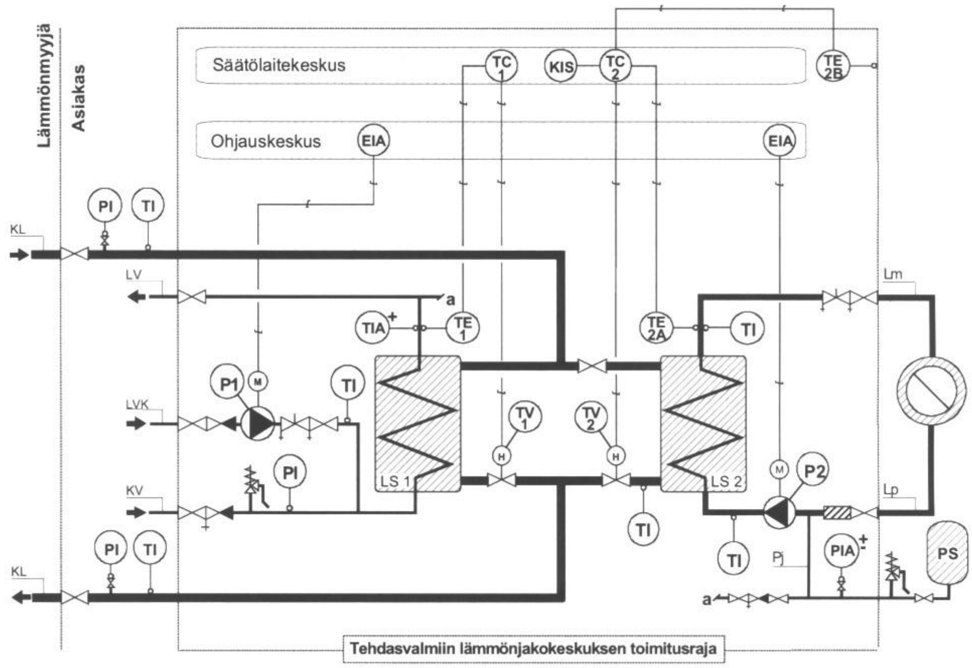


Figure C3. An example of recommended connections in a substation.

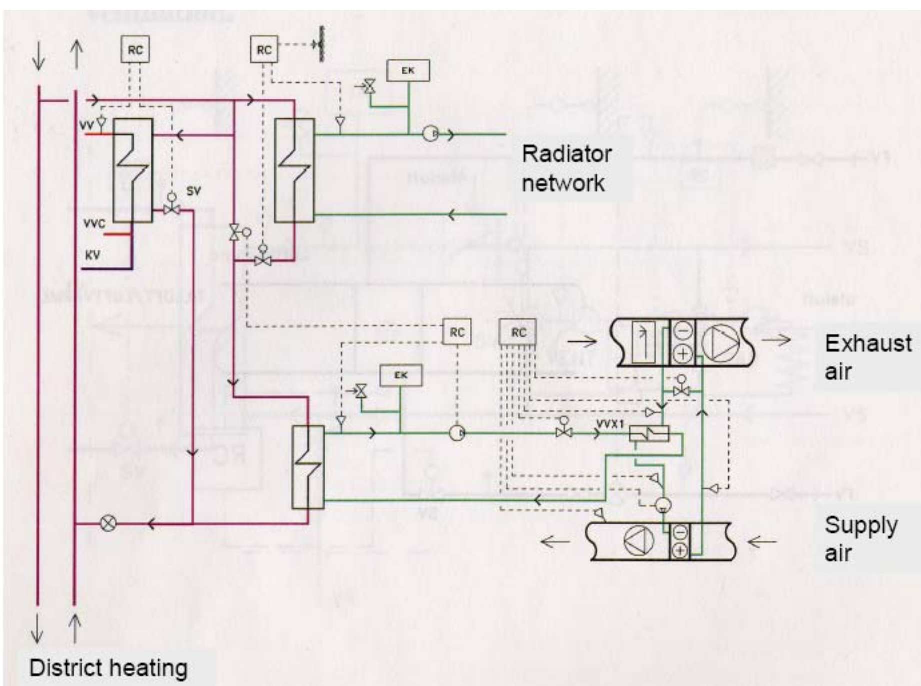


Figure C4. Example connections of a substation where heat from exhaust air and low temperatures are used.

2.4 Customer Acceptance

2.4.1 Method of Metering Energy Use for Billing

The heat used in a building is metered (http://www.energia.fi/). The heating energy meter includes a flow sensor, temperature sensors and a heat amount counter (Figure C1). The flow sensor measures the amount of circulating district heat flow. The temperature sensors are constantly measuring the supply and return water temperatures to and from the building. Based on the measurements from the flow sensor and from the temperature sensors, the heat amount counter calculates the heating energy used for space heating and for hot service water. The heat amount counter automatically takes into account the water density and the specific heat corresponding to the water temperature. The heating energy used is shown in the meter in megawatthours (MWh). The building specific heating energy metering is accurate and reliable.

2.4.2 Automatic Meter Reading

With AMR, power network owners can easily and safely collect data on electricity, water, heating, and gas. AMR saves both time and money. With AMR, the meter readings are directly transferred to the heat producer's client data processing system. Data is transferred over some remote connection, such as a fixed IP-connection, GSM, GPRS or a traditional modem. With remote reading, the heating energy meter is read in defined intervals, which makes monitoring of the heating energy and the heat substation more efficient.

2.4.3 Typical Energy Tariffs

The purchase costs of District heating are determined by the contracted capacity. The costs consist usually of a fixed connection fee, which is customised according to situation. The connection cost to the District heating network for a detached house is about 3.200 in Finland (Pulliainen 2005). The energy fee is composed of a fixed annual demand charge, which depends on the connection capacity, and of an energy unit rate, which depends on the consumed amount of heat. (Seppänen 1995) About 30 percent of the district heating costs consist of taxes, in Finland. Other factors that are influential on the price level are the used fuel, the plant's age, the structure of the conurbation, the effectiveness of the investments as well as the plant's management and the owner's return requirements (Energia 2004).

In Helsinki, the connection fee for District heating is calculated through the following formula:

Water Flow	Connection Fee
0 2 m /h	1620 + 4000 * V + 45 * M
2.2 10 m /h	4820 + 2200 * V + 65 * M
Over 10 m /h	14320 + 1240 * V + 70 * M

where:

V = Contract water flow (m /h),

M = The length of the connection pipe (m).

The value-added tax (VAT) is further added to the connection fee.

The energy unit rate depends on the consumed amount of heat and is of different size depending on whether it is summer or winter. The rate in summer is about half of the winter rate. The rates have changed during time and in Table C1 is seen the size of the rates since 1.7.2002 until today. In the table, it can be seen that the energy unit rate at the moment is 35.12/MWh.

Table C1. The energy unit rate in Helsinki.

Time	Water district heating tariff (€/MWh)	
1.1.200531.03.2005	34.38	Winter price
01.04.2005 30.6.2005	16.82	Summer price
01.07.2005 30.9.2005	17.45	Summer price
1.10.2005	35.12	Winter price

The fixed annual demand charge depends on the district heating connection capacity. Annex 1 lists the charges for different water flows. The annual water flow charge for example for a detached house is 316 (Pulliainen 2005).

From Figure C5 it is possible to see how the fuel price has developed over time. An average of the prices since 1.1.2002 is 4.43 c/kWh for district heating. Even though the prices have been rising steadily during the past 15 years for district heating it is still the cheapest energy source. The price development of district heating depends above all on the fuels' price development and the general interest level. The prices of fuels in Finland depend mainly on the world market prices of oil, natural gas, and coal as well as energy taxation (Seppänen 1995).

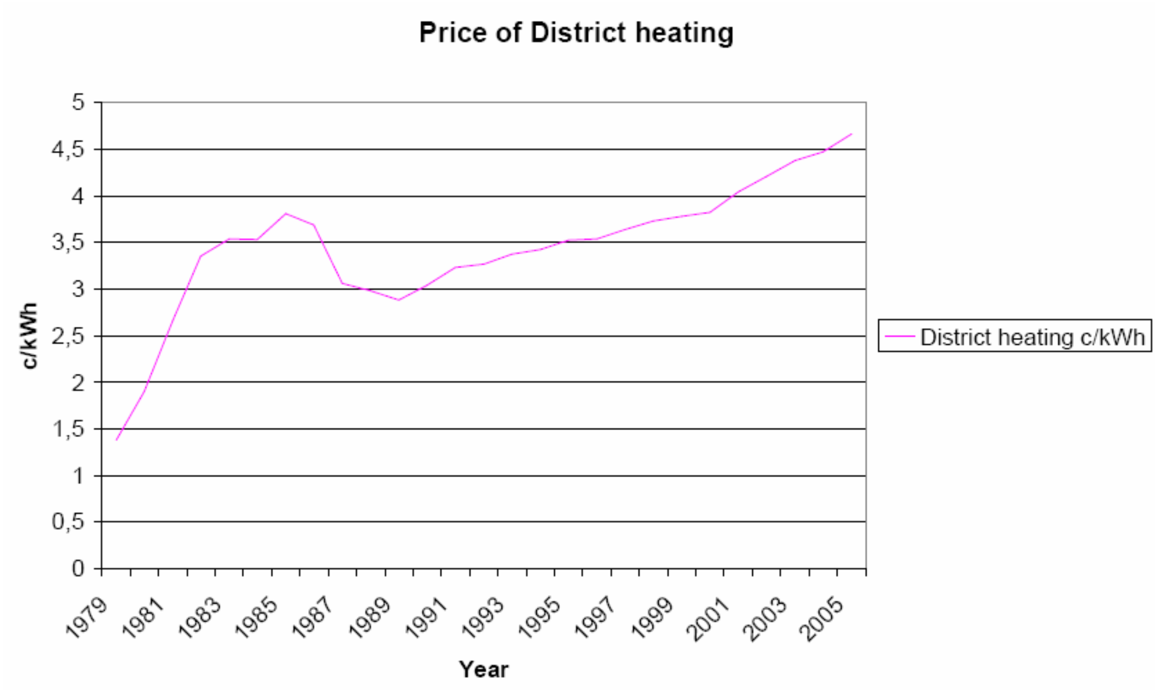


Figure C5. History of fuel prices for District heating in Finland (Energiatilasto 2002).

Concerning the maintenance- and renewal costs, equipment that should be renewed once during a 30-year time interval are the domestic hot water's control valve and servomotor (455), which need to be replaced after 15 years, and the floor and radiator heating pumps (287 respectively 416), which need to be replaced after 20 years. These prices are typical for detached houses in Finland (Motiva 2005).

2.4.4 System Reliability

In Finland the delivery reliability of district heating is excellent even in extremely cold weather (http://www.energia.fi/). The heat breaks due to faults in the technical equipment have been short and their impact on room temperatures have been only a couple of degrees Celsius on average. In Finland the district heat production capacity is about 19,300 MW. The clients' total heat demand is about 15,500 MW when the weather is extremely cold in the whole country.

The heat producers' statistics show that the shortage of district heat per client is annually 1 hour on average (http://www.energia.fi/). Naturally, failures and malfunctions happen due to technical faults in the equipment. Systematic quality control, maintenance and repair, and preventive mainte-

nance of the whole system and its equipment are the main reasons for the good delivery reliability.

2.5 Advantages, Disadvantages, Limitations and Side Effects

2.5.1 Advantages

District heating is a painless and user-friendly heating form for a consumer. Service and maintenance of distributed heating solutions are often more complex.

Due to centralized production, also low-grade fuels can be used in production of district heating. In addition, the fuel is changed quickly if there is no need to change the boiler. In combined heat and power (CHP), 30-40 percent fuel saving is achieved compared to a separated production of electricity and heat.

Due to economies of scale, larger DH systems can cost-effectively use a variety of energy sources (Ala-Juusela 2004). This flexibility improves the security of supply and is generally not achievable by an individual buildings' heating system.

District heating not only offers excellent opportunities for reducing environmental pollution, but also for achieving the goal of saving energy. It is an extremely flexible technology that can make use of any fuel including the use of waste energy, renewables and, most significantly, the application of combined heat and power (CHP) (http://www.iea-dhc.org/).

When using CHP, the use of fuel is optimized with minimum wastage. It is estimated that about 11 percent of the total primary energy consumption can be saved with CHP and about 20 percent of the use of fossil fuels (http://www.energia.fi/), respectively.

District heating enables poly generation, various distribution methods inside the building, including low temperature systems.

2.5.2 Disadvantages

District heating is a capital-intensive form of energy. It requires long-span energy solutions. So, the payback period is quite long.

There are disturbances during the construction work of the district heating network. If the pipes are installed under ground the streets need to be opened.

The electricity production is liberated in electricity network of Finland. Customers can order their electricity among many alternative suppliers. Liberated heat trade can be carried out by the same principle as electricity trade in local district heating network (Sipilä et al. 2005). However, at the moment DH companies are typically municipal owned in Finland, which gives them a monopoly in the market.

2.5.3 Limitations

District heating is available only in defined areas.

3 ECONET Module

Building energy systems include systems for heating, cooling, service water, and air treatment. Building control and automation systems also have an important role in the building energy management. Naturally, there are various possible solutions for these systems. Sometimes, a system may take care of several energy functions, e.g., in addition to ventilation, air conditioning may also handle space heating and cooling so that separate heating and cooling systems are not needed. During the building design, suitable energy sources are selected for the building energy systems.

An ECONET module is part of the building air treatment system. In the ECONET concept, all thermal functions of an air handling unit are integrated in the same circuit for heat recovery, heating and cooling. The key elements of the ECONET module are described in this section. If necessary a building may also include additional space heating and cooling devices or systems. The ECONET is suitable for a variety of buildings. Some applications are presented in section 4. There are number of possible energy sources for the ECONET module, including district heating. Section 5 discusses these possibilities and their integration to the ECONET air handling unit.

3.1 ECONET vs. Traditional Air Handling Unit

A traditional air handling unit (Figure C6) usually consists of different components such as dampers, filters, fans, heat recovery from exhaust air, followed by a heating and cooling coil (Amelung and Waldschmidt 2005). The two heat recovery coils (exhaust air & fresh air) and the normal heating and cooling coils (supply air) are separate components each having separate hydraulic systems with pumps, valves etc. These components are never used at the same time. Taking this into consideration it is not very environmentally economic to waste energy for to transport air through these components in this manner.

The ECONET innovation simplifies the heat transfer circuits. Compared to a traditional system larger heat transfer area exists in an ECONET system in certain operation modes, even though the total heat transfer area is smaller. This makes it possible to use low temperature levels.

ECONET is a packaged liquid-coupled heat recovery system (Figure C7) with a unique optimizing control system (Sundelin 2004). The ECONET system is using the heat recovery coil in the supply air section of the HVAC also for normal heating respectively cooling. The ECONET system requires fewer components such as heating/cooling coils, pumps, valves, piping, insulation etc. It results also in a shorter and more compact air handling unit. Additionally, the heat recovery efficiency using ECONET is improved by approximately 15 to 20 percent compared to traditional run around coil systems (Amelung &Walschmidt).

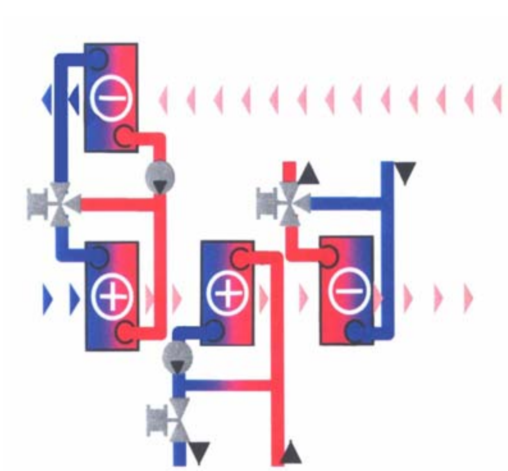


Figure C6. The traditional system.

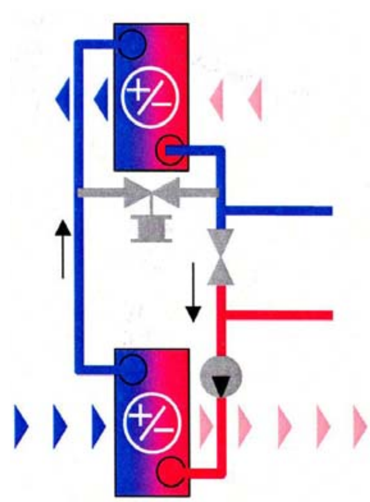


Figure C7. The ECONET system.

ECONET is designed so that it can fully use the possibility to reduce the district heat return temperature in cold weather. This feature is illustrated in the lowest line (the red one) in Figure C8, i.e., the district heat return water temperature decreases when the outdoor air temperature decreases. At -30 °C outdoors, the difference between the district heat supply and return temperatures has almost doubled (ABB 2002).

The main properties of ECONET® are:

- one integrated heat transfer circuit
- optimal heat transfer
- profitable temperature ranges.

It is soon already 10 years since the planning of ThermoNet started at ABB. It all started with a development of Indirect Evaporative Cooling for air handling units. From this was further developed an effective heating/cooling recovery unit. The first pilot project was in use 1994 in Tampere in Finland. Since this the development of the product was fast. By the end of 1999 ABB had participated in nearly 125 projects and sold about 235 ThermoNet units. In 1999, the ThermoNet units were given a new name: ECONET and where integrated into the EU2000 concept. Since then the ECONET units have been delivered by the FläktWoods Group.

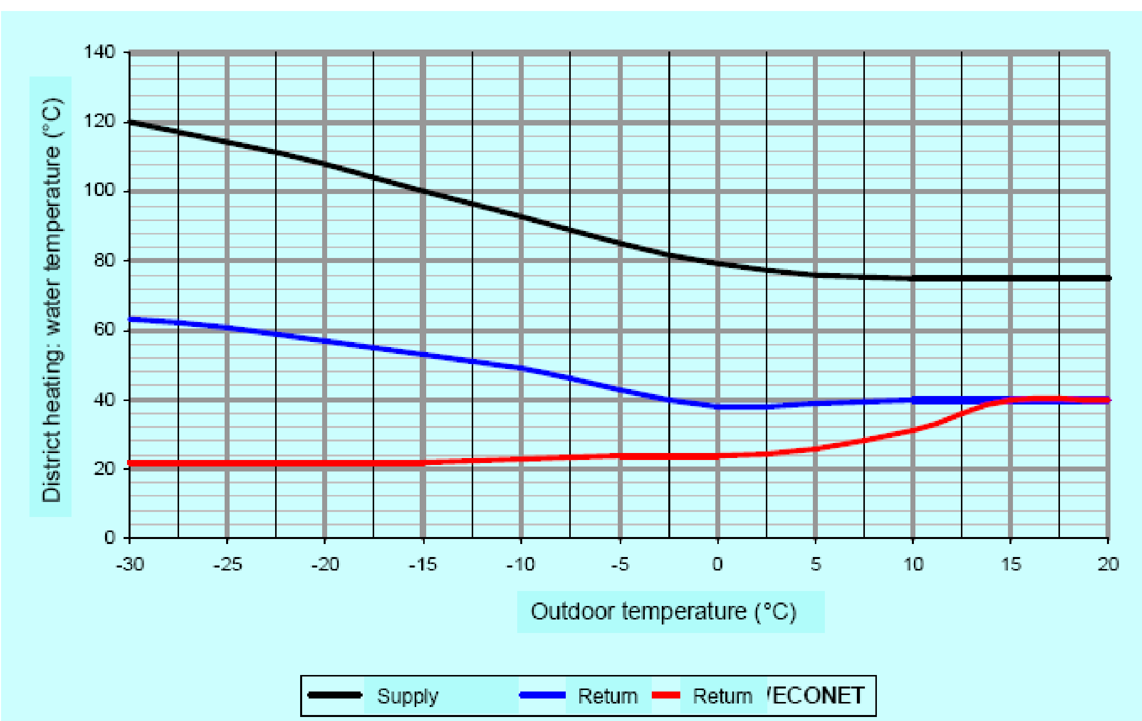


Figure C8. Typical district heat supply and return water temperatures with a traditional district heating system and with an ECONET system.

The ECONET units are a natural continuation of the ThermoNet thinking. All the excellent advantages that were achieved with ThermoNet still exist in the ECONET concept. The only essential difference is the delivery scope. Today the ECONET delivery is in most cases limited to air handling units with the ECONET module only. However, in some cases the delivery scope has still been a system turnkey delivery.

3.2 Operation Principles

3.2.1 Dimensioning

When dimensioning the heating situation for ECONET attempts either to use low temperature heating water (example 1) or large temperature differences for the heating water (sample 2) (FläktWoods 2005).

3.2.2 Example 1

In the heating situation in Figure C9 a heating water temperature of about +26 °C is sufficient to heat 8.5 m^3/s air from -20 °C to +20 °C (FläktWoods 2005). Supplementary heat is supplied to the recovery circuit via an external exchanger with a temperature of e.g., +30 °C (3.0 L/s). The return water returned to the heat exchanger is about +14 °C whereby the return water in the heating system is then approximately 19 °C. In this situation, the antifreeze protection is operational, and in being so, heat recovery is limited.

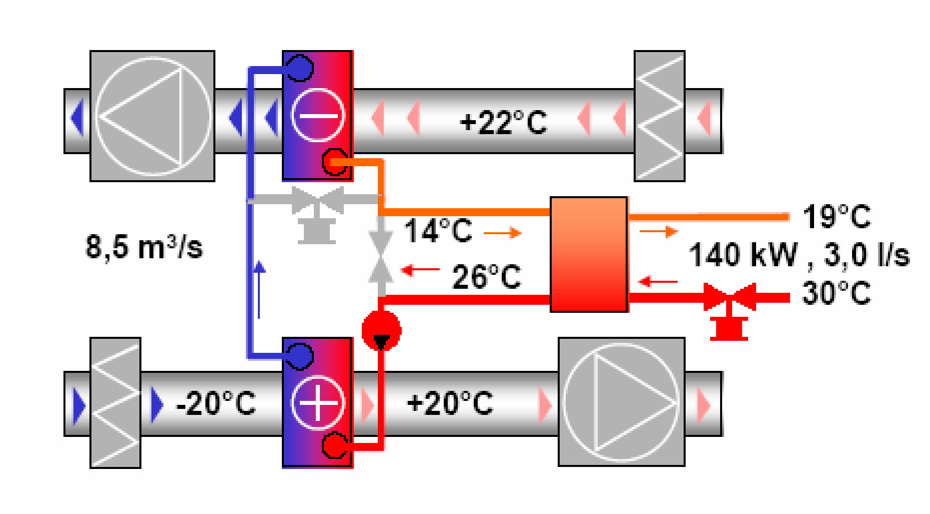


Figure C9. ECONET heat transfer with low temperature heating water.

3.2.3 Example 2

The same operating circumstances as previously, but with a supplementary heating temperature of 60 °C (Figure C10; FläktWoods 2005). The temperature difference for the additional heating (supply/return) is great, approximately 45 °C, which gives a small liquid flow (0.74 L/s). In this situation antifreeze protection is operational and with that heat recovery is limited.

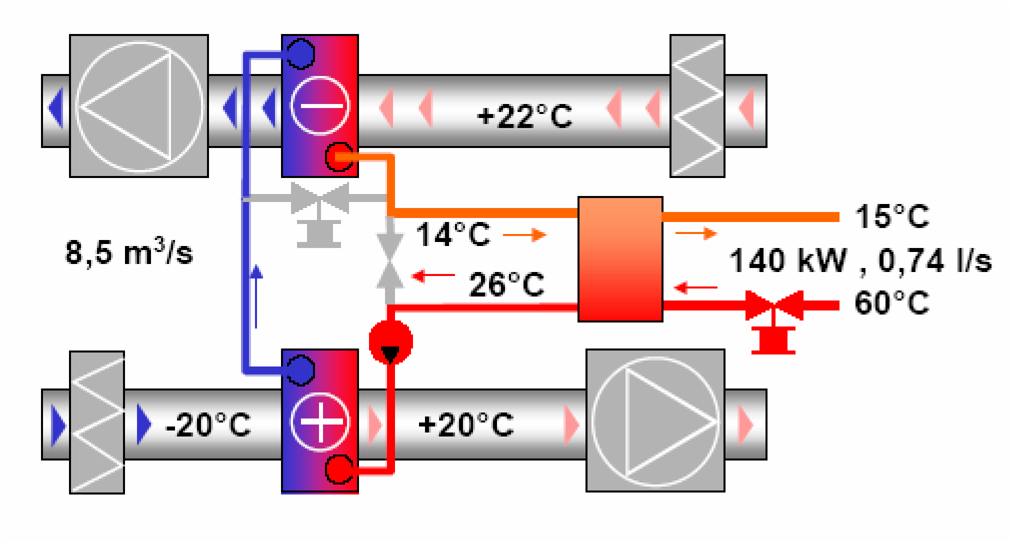


Figure C10. ECONET heat transfer with large t for the heating water.

Only the supply air coil (not in case of cooling recovery) is used to cool the air, i.e., in this case the exhaust air coil is idle. A high return temperature on the cooling water is obtained, which gives a small liquid flow (FläktWoods 2005).

3.2.4 Example 3

In the cooling instance in Figure C11, 8.5 m^3/s air is treated from +25 °C/50 percent to +15 °C. A cooling water temperature of about +12.5 °C is needed. The additional cooling is supplied to the recovery circuit (cooling circuit) via an external exchanger with a temperature of e.g., +7 °C. The return water, which returns to the heat exchanger, is about +23 °C whereby the return water in the cooling system is then about 21 °C (FläktWoods 2005).

The cooling effect requirement is 103 kW and the requisite liquid flow is 1.75 l/s. A conventional cooling system with the cooling water at +7 °C/+12 °C would required a liquid flow of about 5 l/s. As the average

temperature in the ECONETcoil is higher than in a traditional cooling coil, even the cooling effect requirement is slightly lower (the higher the average temperature on the liquid side across the cooling battery the less condensing on the air side).

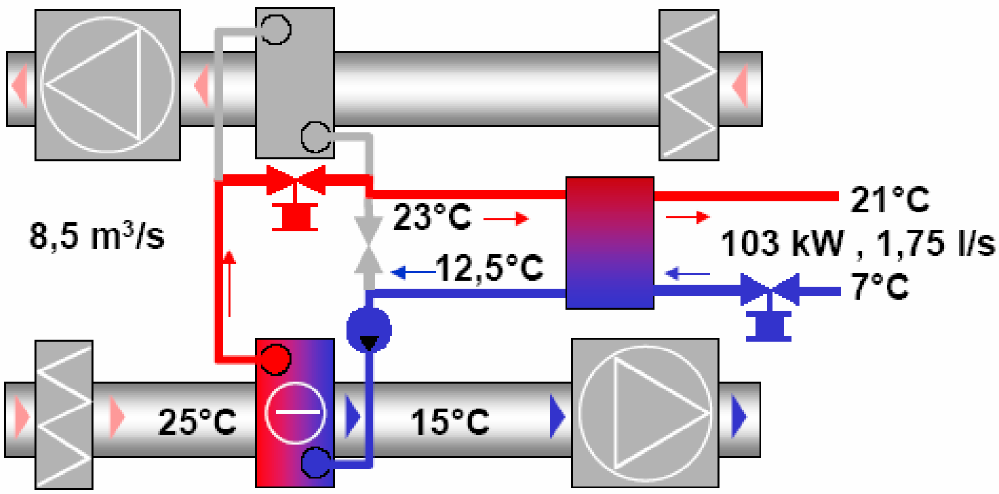


Figure C11. ECONET cooling transfer in a cooling instance.

Note that just as in the heating instance the fluid in the recovery circuit is an ethylene glycol mixture, i.e., provided that the cooling water is water the circuits should be separated with a heat exchanger.

3.2.5 Control Functions

The heat recovery function is controlled by the ECONET control box. Specific functions for the AHU are controlled by a separate control box (not included in the ECONET delivery). ECONET is a part of the sequence to get the set point of the supply air temperature.

3.2.6 Simplified Function of the ECONET Control Box

Cooling recovery, On/Off

A pump regulates the liquid flow to an optimal position for cooling recovery, corresponding by-pass valve will close.

Supplementary cooling, On/Off

A pump regulates the liquid flow to optimal position for supplementary cooling.

Heat recovery, 0...100 percent

A pump starts at minimum position and the corresponding valve goes from open to closed, then the pump goes from minimum position to optimal position (optimal heat recovery).

3.2.7 Frost and Ice Protection

Frost protection (Protection against frost formation on the exhaust air coil [air side].)

The measured liquid temperature is restricted to go below a specific temperature (approximately-3 °C) for frost protection by regulating the liquid flow with the pump from optimal liquid flow to increased liquid flow.

Risk of frost formation: When the measured liquid temperature goes beyond the defined alarm value (approximately -10 °C), an alarm is given.

Ice protection (Protection against ice formation in the heat exchangers for supplementary heating/cooling [water side].)

The liquid temperature at a defined point is restricted to go below a specific temperature (approximately 6 °C) for ice protection by regulating the liquid flow with the pump from optimal liquid flow to increased liquid flow.

Risk of ice formation:
When the defined liquid temperature goes beyond the defined alarm value (approximately 2 °C), an alarm is given.

3.3 Advantages of ECONET

Advantages of ECONET for the consumer (ABB 2002) are:

- technological benefits
  - simpler technical solutions
  - demand based control
  - more environmental friendly, for example with a reduced need of refrigerants
  - increased availability and operation safety
  - frost protected system
  - smaller installation space needed
  - easy to implement district cooling

- cost benefits
  - great energy savings because of increased energy reuse, demand control of the air conditioning system and use of indirect evaporative cooling when feasible
  - reduced peak demands for heating and electricity
  - lower investment costs
  - reduced demand of heating/cooling/electric power and energy
  - lower energy fees
  - lower pumping costs due to frequency converter control
  - lower operation, service and maintenance costs.

The main advantages of typical ECONET in different operation modes (Hyvärinen & Kohonen 2000) are:

- the possibility to use large temperature difference between supply and return temperatures in cooling
  - supply +6 +16 °C
  - return +18 +30 °C
- the possibility to use large temperature difference between supply and return temperatures in heating
  - supply above +50 °C
  - return +15 +20 °C
- the possibility to use low temperatures in heating
  - supply +25 +40 °C
  - return +15 +20 °C.

Building level advantages of ECONET (Hyvärinen & Kohonen 2000) are:

- good electricity efficiency (smaller pressure drop than in equivalent traditional system)
- small heating energy consumption (efficient heat recovery)
- easy to use free energies also with low temperatures
- smaller costs of district heat flow and for joining the district heating network.

Advantages of ECONET in energy production (Hyvärinen & Kohonen 2000 & ABB 2002) are:

- possibilities to use free energies, low grade thermal energies, and district heat return water in buildings
- reduced district heat return temperature
- more efficient use of district heating network
- increased efficiency in electricity and heating production
- lower costs for pumping of district heat water

- decreased heat losses in the distribution system
- improved system capacity and mechanical solutions reduce the peak loads in production
- more customers can be connected to the existing district heating network due to reduced water flow
- the investment costs of the expansion of the district heating network is reduced
- environmentally friendly techniques are used
- reduced emissions from production
- higher profitability in energy sales
- reduced fuel input when biofuel is used.

3.4 Suitability of ECONET

The suitability area of the solution is large and system parts and solution concepts are developed in a way that complete solution models can be found to all important, potential application areas (Design Manual of ThermoNet Systems).

The ECONET system is especially suitable in the following situations:

- Where the indoor conditions and their control have high requirements
- When a combination of heating, cooling, heat recovery and cooling recovery are included
- When retrofitting or upgrading an existing system
- Where there is low temperature waste or free energy available
- If there is district heating/cooling available
- If there is a clear advantage of a size reduction of the district heating's contracted water flow or if it is possible to be connected cheaply to the return water
- When variable air volume is a good solution because of operating times, load variations or forecasted changes
- If a liquid circulated heat recovery from the return air is anyway a good solution, e.g., where:
    - there is a risk of contamination, such as in hospitals where the air flows cannot mix
    - there are distributed AHUs
    - there are large air volumes in the AHUs
- When cooling is needed, but it can be satisfied with indirect evaporative cooling
- Where full optimization from an energy, hygiene, and space point of view is required.

Situations when the ECONET is less attractive are:

- When the required level of the indoor air only fulfills the minimum regulations in the building code
- When there is cheap waste energy available, in a way that heat recovery is not profitable in general
- Where there are small air flows, e.g., less than 0.6 m^3/s
- When air heating can be realized with pure return air and ventilation peak operation time is very short
- When heat recovery is not practical.

3.5 Comparison of an ECONET System and a Traditional Liquid Heat Recovery System

Amelung and Waldschmidt (2005) compared an ECONET system to a traditional liquid heat recovery system in simulations. The data in Tables C2 to C5 summarize the results. The conditions are:

- Air handling Unit: Type EU-50, max airflow 5.56 m^3/s (20 000 m^3/h)
- Temperature duration curve: Berlin / Germany
- Running time: 24 h/week, 7 days
- Supply air temperature heating period: 20 °C
- Supply air temperature cooling period: 18 °C
- Outlet temperature ECONET-supply coil, cooling period: 14 °C (dehumidification)
- Exhaust air temperature: 22 °C, 40 percent (winter) ; 24 °C, 50 percent (summer)
- Air flow: 100 percent fresh air.

Table C2. Savings in the heating situation.

Heating	Traditional System	ECONET	Reduction		Impact
Supply heating	72 kW	44 kW	28 kW	39 %	Lower connection fees
Heating water temp.	60 / 40 °C	60 / 20 °C			
Heating water flow	0.86 l/s	0.26 l/s	0.59 l/s	69 %	Lower energy & connection fees due to liquid flow Reduced dimensions of pipework
Heating energy	34.2 MWh	9.3 MWh	24.9 MWh	73 %	Lower energy fees

Table C3. Savings in the cooling situation. (IEC = Indirect Evaporative Cooling).

Cooling	Traditional System	ECONET with IEC (adiabatic cooling)	Reduction		Impact
Supply cooling	173 kW	93 W	80 kW	46 %	Smaller chillers
Cooling water temp.	6 / 12 °C	6 / 19 °C			Higher COP
Cooling water flow	6.87 l/s	1.70 l/s	5.16 l/s	75 %	Reduced dimensions of pipe work
Cooling energy	112 MWh	88 MWh	24 MWh	21 %	Lower energy fees

Table C4. Impact on electrical energy for the fans.

Fans	Traditional System	with IEC	Accumulation	
Electrical energy	114 MWh	121 MWh	+ 7 MWh	+ 6 %

Table C5. Size of the air handling unit.

Length of Air Handling Unit	Traditional System	ECONET	Reduction		Impact
	11.116 m	9.616 m	1.5 m	13 %	2.6 m 2 more free space in the technical area

Another benefit of ECONET concerning heating of air is:

- the possibility to use “free and cheap” heating energy such as waste / process / condensate / return water of district heating.

Other benefits with ECONET, concerning cooling of air are:

- A large T for the cooling water is very interesting concerning district cooling
- Lower fee will appear, due to decreased cooling water flow

The exhaust air humidification (IEC) leads to a slightly higher consumption of electrical energy for the fans (Table C4), but it also leads to essential savings of cooling energy (Table C3).

4 ECONET System Concepts for Heating and Cooling of Buildings

ECONET system can be applied to a variety of building types including hospitals, swimming halls, offices, industrial buildings, residential high-rise buildings etc. Generally speaking ECONET is suited for almost all kinds of applications where heat recovery is possible.

4.1 Supermarket Application

The main advantages of ECONET in a supermarket application are (Hyvärinen & Kohonen 2000):

- the special requirements of a grocery department, a consumer goods department, cash desks and auxiliary areas are taken into consideration
- the efficient recovery and use of free energies (condensation heat, heat energy from clients and lighting)
- its ability to simultaneously take heating and cooling into account
- its ability to use a low temperature system
- its quick construction and renovation time
- its minimized environmental impacts.

An application of ECONET system for supermarkets is presented here (Figure C12) (Ala- Juusela 2004). In a supermarket, waste heat is available, the ventilation has a demand based control, and the cooling is environmentally friendly because of the low demand. The exploitation of condensation heat, waste heat, and excess energy in a ECONET system is based on two factors: an air heating system that uses low temperature technology, and efficient energy recovery. By applying ECONET technology, the consumption of purchased energy may be cut by more than one half when compared to conventional solutions, and electrical consumption may be reduced to one third. The ECONET low temperature system is able to use district heating return water from other properties, reducing peak loads by 60-70 percent.

In Maxi ICA Market in Haninge, Sweden, an ECONET application was used. The measurements show that nearly 100 percent of the heating energy demand of the air handling and heating of the sales space, is covered with condensing heat from the food refrigeration machines. Only when the outdoor temperature is at its lowest is additional heat needed from the district heating. The demand based control of the fan rotation speed is valuable. Most of the operating time the fans have ran on minimum airflow but there have still been resources for covering the demand for peak loads (Maxi ICA 1998).

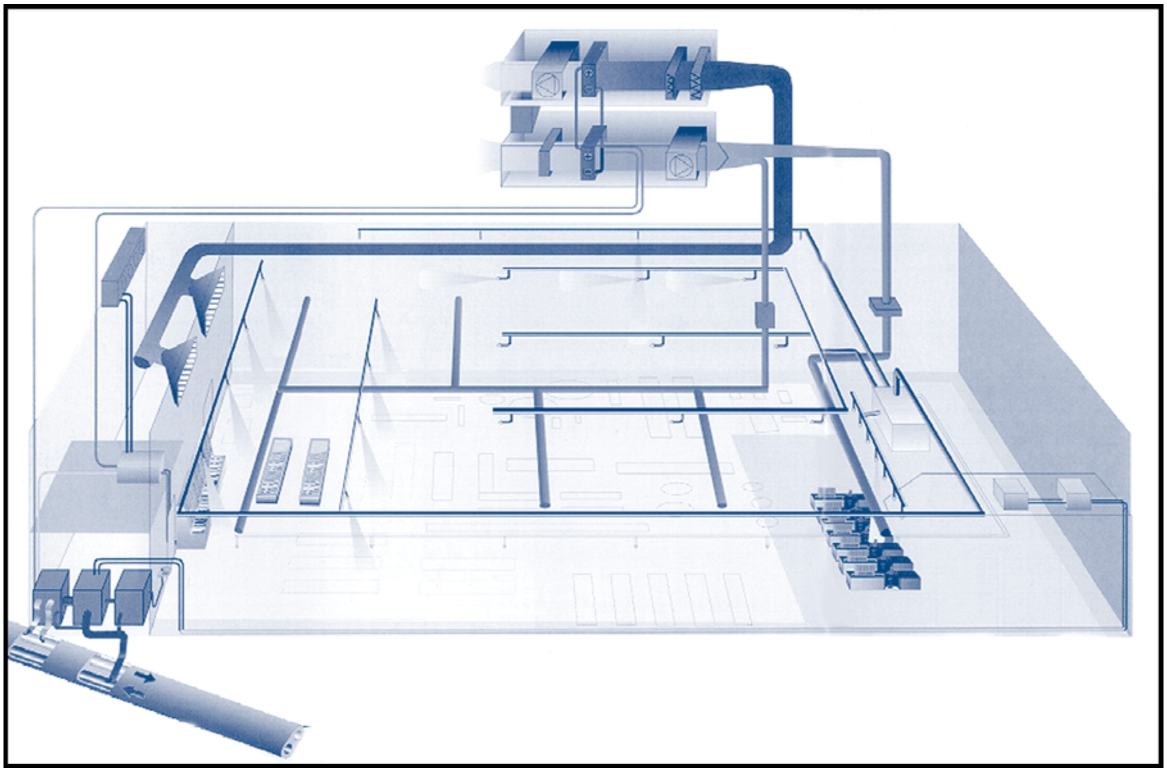


Figure C12. An ECONET system for a supermarket.

Heating

In supermarkets, the relative size of grocery departments is large. Consequently, a large volume of condensation energy is abundantly available, and its temperature is well suited for use by the ECONET air heating system. Primarily for this reason, shop spaces are warmed by air through an impulse system. The air heating system is also able to control the rapid load fluctuations typically found in supermarkets. Vestibules are fitted with air circulation equipment connected to the ECONET network (Ala-Juusela 2004).

Heat Sources and Heat Recovery

Heat sources include heat recovered from exhaust air, condensation heat from refrigerated grocery department display cases, and supplementary energy sources such as district heating, electricity, natural gas, or oil. With the ECONET system, the connection to district heating can be made in an exceptionally economical fashion: ECONET is able to take advantage of return water flowing from other properties to the combined heat and power plant. This water contains sufficient energy that the ECONET system can use.

Cooling

The cooling efficiency of by refrigeration equipment, along with indirect evaporative cooling, is usually sufficient as a source for cooling energy.

4.1.1 Air Systems

Air heating is implemented using an impulse system that improves the operation efficiency of warmed air. Heated air, because it may be quickly adjusted and controlled, is the most effective alternative. Air conditioning is implemented using a single technology centre. If necessary, air conditioning operates during the day either using return air or fresh air and during the night using return air. The air flow and temperature are controlled so that the total benefit derived from the recovery of condensation heat, as well as from the savings in fan energy will be as large as possible (Ala-Juusela 2004).

Air Distribution

Efficient air distribution can be used to achieve an economical heat balance. Air distribution is done to maintain temperature layers in cooling situations. In heating situations, temperature layer formation is blocked using Dirivent impulse system (vertical distribution for indoor air).

Control System and Remote Supervision

The ECONET system's ability to control the indoor climate while effectively using heating energy created in supermarkets is based on an energy use and control system designed for that purpose (Ala-Juusela 2004). Additionally, through the program, the system can be controlled and supervised remotely in real time, and necessary adjustments and alternations to the ECONET system may be made by experts from remote locations.

4.2 Office Application

The main advantages of ECONET in an office application are (Hyvärinen & Kohonen 2000) are:

- its integrated energy production and usage
- Its efficient integration of thermal energy
- its system optimized heating, cooling and ventilation
- its system design of modules for energy production, ventilation and control.

The office building consists basically of an office space, meeting and representation rooms, dining- and kitchen facilities. Also the needed service spaces as social space, technical space, storage- and archives space, parking space etc. are included. These different kinds of spaces have varying requirements, operating times and loads (Design Manual of ThermoNet Systems).

An office building with high indoor climate requirements is equipped with mechanical cooling and a room specific temperature controller. The ECONET system is used for:

- optimization of the energy economy and power demand. In office buildings several alternative air distribution solutions and terminal units can be connected to the ECONET system. Especially well suited are:
  - air volume controlled solutions
  - combined ceiling cooling and air volume controlled solutions (Design Manual of ThermoNet Systems).

In addition to purpose of use also naturally the type of space (a room-, combined- or open-plan office) affect to space specific solutions. The possibilities of using raised floor and dropped ceiling installations also affect the choices made (Design Manual of ThermoNet Systems).

Connecting an indirect evaporative cooling to the ECONET systems is always worth considering in office buildings (Design Manual of ThermoNet Systems).

4.3 Hospital Application

The main advantages of ECONET in a hospital application are that:

- it fully separates supply and exhaust air flows, preventing cross-contamination
- it improves on temperature efficiency compared to a traditional liquid circulated system
- it has efficient components, i.e., reduced operating costs
- its reduced district heat return temperature
- its reduced contracted water flow
- it allows full optimization from an energy, hygiene and space point of view.

Hospitals suit well for ECONET because of the long operating times, the ventilation is demand driven and because of indirect recuperative heat recovery and a system that is frost protected (ABB 2002). In addition, the hygiene requirements are strict in hospitals, i.e., the air flows cannot mix. Also there may be water from laundries or kitchens available for heating when a low temperature system is used. These make ECONET a very attractive solution for hospitals. In chapter 6.1, a case example of a hospital application is presented in more detail.

4.4 Residential Buildings

The main advantages of ECONET in a residential application are its:

- efficient heat recovery
- fully separated supply and exhaust air flows preventing odor transfer
- ability to deliver required additional heat to the same heat transfer circuit
- ability to easily include cooling afterwards
- ability to reduce district heat return temperature, possibly resulting in lower connection fees and energy tariffs.

Including a mechanical ventilation is a way to improve indoor air quality in residential buildings (ABB 2002). Then an ECONET system with radiators or floor heating is a good solution. Figure C13 shows a schematic diagram of an ECONET system with radiators in a residential building.

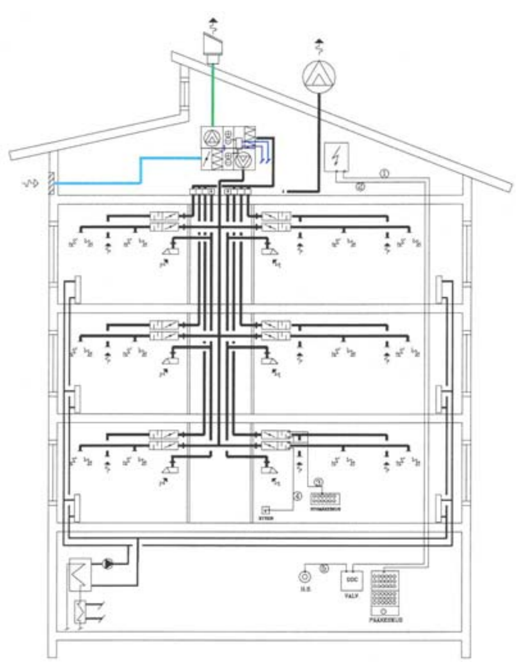


Figure C13. An ECONET system in a residential building.

4.5 Summary of Main Advantages of ECONET in Different Buildings

Table C6 lists the main advantages of ECONET in different buildings.

Table C6. Main advantages of ECONET in different buildings.

Application Type	No. of Installations (between 2000 2005)	Advantages
Supermarket	50	1) The special requirements of a grocery department, a consumer goods department, cash desks and auxiliary areas are taken into consideration 2) The efficient recovery and use of free energies (condensation heat, heat energy from clients and lighting) simultaneous heating and cooling are taken into account low temperature system can be used quick construction and renovation time minimized environmental impacts
Office	300	3) Integrated energy production and usage efficient integration of thermal energy system optimized heating, cooling and ventilation system designed modules for energy production, ventilation and control
Hospital	200	4) Fully separated supply and exhaust air flows preventing cross-contamination 5) Improved temperature efficiency compared to a traditional liquid circulated system efficient components, i.e., reduced operating costs reduced district heat return temperature reduced contracted water flow 6) It allows full optimization from an energy, hygiene and space point of view
Residential	100	7) Efficient heat recovery fully separated supply and exhaust air flows preventing odor transfer 8) Required additional heat is delivered to the same heat transfer circuit 9) Easy to include cooling afterwards reduced district heat return temperature, possibly resulting lower connection fees and energy tariffs

5 Integrated ECONET System Solutions (ECONET Energy Sources)

5.1 ECONET with District Heating

The ECONET system is suitable both for new construction and for renovation. It suits especially well for cases where district heat return water or process waste energy are available.

5.1.1 Connections to the District Heating Network

Because the ECONET® system can function at low temperature levels, it can be connected in series to the heating network of the district heating return network in a building's district heating substation (Ahonen et al. 1995). Connection in series can be done also in the heat exchange pipework of a building when heating and air conditioning circuits are connected to the district heating network via a common heat exchanger. The ECONET® system can also be connected directly to the district heating return pipe. Then the direction of the district heat flow may not vary in the return line.

So, the connection of the heating circuit to the district heating network can be done in several ways depending on the character and extension of the plant. (The ECONET-unit always has an own inner circuit supplied with a circulation pump) (Design Manual of ThermoNet® Systems):

1. Connection through an indirect water circuit. The secondary circuit is used mainly in large networks, when there are several scattered AHUs or within the same district heating connection (Figure C14).
2. Through direct connection. On the secondary side of the circuit is the ECONET heat carrier, that serves the AHUs in the district heat substation. The heat exchangers can be located either in a separate heat distribution room or in a ventilation engine room.
3. District heating is connected straight to the ECONET. The heat exchangers are directly included in the unit's heat exchange circuit.
4. The return water of the district heating is connected to the heating circuit of the ECONET.

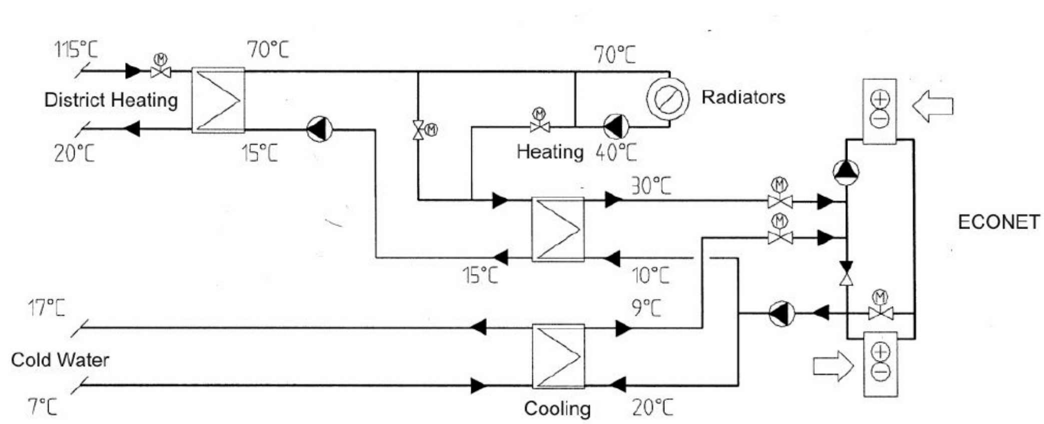


Figure C14. Connection through an indirect water circuit.

The Return Water from Radiators

The design temperatures of the radiator network are normally 70/40 °C in new buildings and in old ones usually even higher (*Design Manual of ThermoNet® Systems*). The return water can be used as a heat source, because the radiator network's return water temperature is high enough for the ECONET unit. The power sufficiency gained from the return water has to be checked in different operating situations, because the temperature of the radiator network's return water reduces when the outdoor temperature increases.

If the ECONET connection is made through a water circuit the radiator return water is led into the heat exchanger of the ECONET. If there is a direct connection, the district heating heat exchangers of the radiator network and the ECONET circuits are connected in series.

There are cases with connections in series when non-simultaneous building loads may cause problems with flows (Ahonen et al. 1995). Then adequate district heating energy with the ECONET® system can be ensured with a connection where supply district heating water to the district heating substation is used when necessary. This is also done if there is not enough district heating return water or other heating network return water available.

Three-Pipe Connection

In an ECONET system the temperature of the return flow differ relatively little between cooling and heating situations (Design Manual of ThermoNet® Systems). So, the return pipes can be combined and usually left thermally uninsulated. In indirect connections this is sometimes possible also in heating and cooling water networks. This may have a great impact on extensive networks.

Impacts of ECONET® on energy consumptions and costs

Ahonen et al. (1995) studied with computer simulations the impacts of the district heating connected ECONET on the energy consumption and costs of buildings and energy utilities. The reference systems in an office building were a constant air volume system and a variable air volume system. In a multistory residential building, the reference systems were a mechanical

exhaust ventilation system and a mechanical supply and exhaust ventilation system. The results are briefly summarized below.

Building Level Impacts

The ECONET system reduces the district heat return temperature and total flow especially during peak heat demands. Based on the simulations the district heat return temperature of the ECONET system during peak heat demands was 20 °C lower in the office building and 15 °C lower in the multistory residential building than the return temperature of the reference systems. In the office building the district heat flow of the ECONET system was 30 to 50 percent lower, and in the multistory building 20 to 40 percent lower, than the flow of the reference systems.

In the office building the ECONET system used 12 to 34 percent less heating energy, and in the multistory residential building 9 to 29 percent less, than the reference systems because of better exhaust air heat recovery and demand controlled ventilation. In the office building the ECONET system used even 70 percent less electricity than the constant air volume system because of its smaller air volume and 5 to 15 percent less electricity than the variable air volume system owing to the smaller need for cooling electricity. The ECONET system did not save electricity in the multistory residential building.

In the office building the annual operating costs of the ECONET system were 43 to 68 percent less than the costs of the constant air volume system and 18 to 50 percent less than the costs of the variable air volume system. In the multistory building the costs of the ECONET system were 0 to 36 percent less than the costs of the mechanical supply and exhaust ventilation system. The cost savings in the office building were due to the reduced heating energy and power, reduced electricity demand of the cooling and also the electricity demand of the fans if the reference system is a constant air volume system. The cost savings in the multistory residential building were due to the reduced heating energy and power.

Energy Utility Level Impacts

Ahonen et al. (1995) studied the impacts of an ECONET system on annual operating costs of an energy company producing combined heat and power. These costs consist of:

- fuel costs of combined heat and power

- fuel costs of the plant operating on peak heat demand
- annual power fees of natural gas
- annual fees and energy fees of wholesale purchase of electricity.

Figure C15 presents the direct impacts that the ECONET system may have on the mentioned annual variable costs.

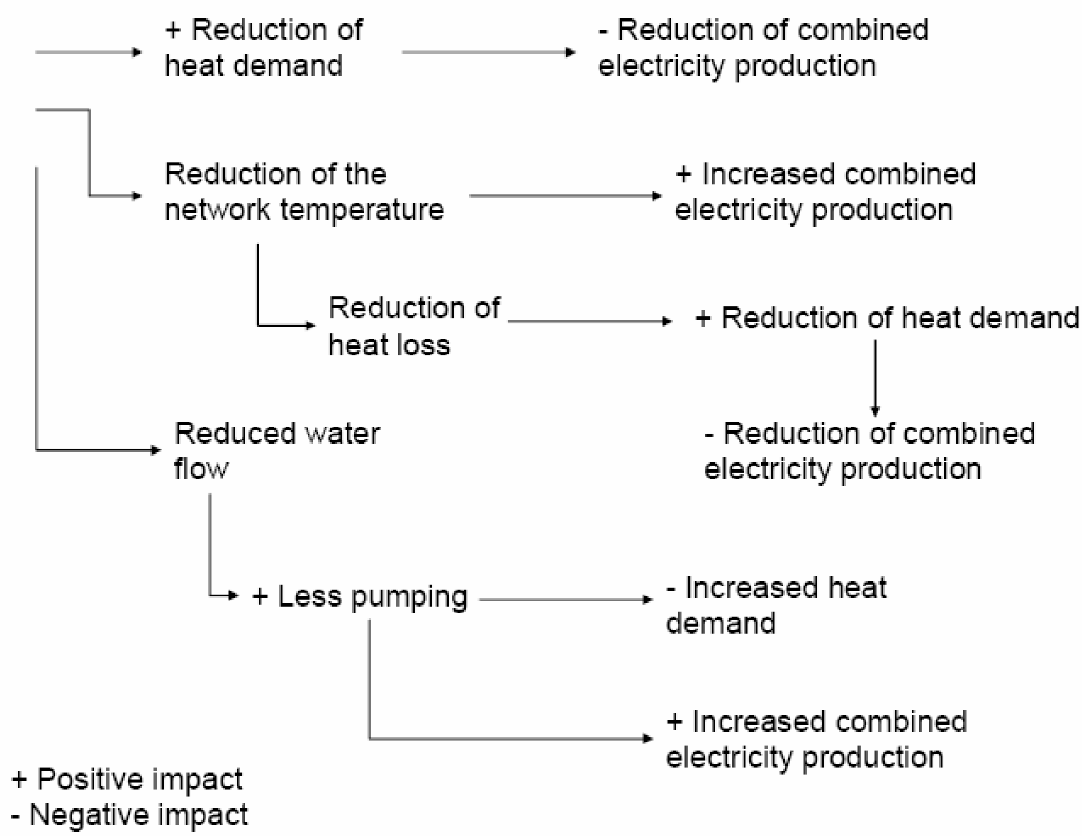


Figure C15. Impacts of an ECONET system on annual running costs of an energy system.

It has been estimated, that a 1 °C reduction in the district heat return temperature means a reduction of about 7 percent in the pumping energy and an 0.8 percent reduction in heat losses of the district heat transmission. Furthermore, it means an increase of about 0.11 percent in the electricity production of the combined heat and power production. The 1 °C reduction in the district heat supply temperature means seven times more electricity than the 1 °C reduction in the return temperature. In the cases studied the utility saved 0.5 to 3.3 percent of its annual operational costs when 6 to 30 percent of the total ordinary energy consumption was replaced by the ECONET consumption. The cost savings were mainly due to energy savings. In one case studied, in which the district heat maximum supply

temperature was reduced from the reference system's 115 °C to the ECONET system's 90 °C, the utility annual operating cost savings amounted to 2 to 3 percent. In this case the energy consumption of both systems was equal.

5.2 ECONET with District/Local Cooling

Helsinki Energy installed its first district cooling system in summer 1998, through a pilot project designed to supply industrial and office users in the Pitäjänmäki area of the city.* This pilot project, which received funding from the EU's Thermie programme, as a Demlocs demonstration project, was implemented in cooperation with ABB and Denmark's Herning Kommunale Värker.

The target of Demlocs project was to demonstrate how existing or new buildings can be heated and cooled with low-grade thermal energy by means of advanced CFC- and HCFC-free technology (Demlocs 1999). The second target was to demonstrate, how much energy could be saved with optimized global energy management concept integrating energy production, transfer and consumption and using most advanced technology, to the benefit of resources and environment. Both targets were achieved in Helsinki.

In general, a cooling centre concept may include a heat energy supply system, a cold energy distribution system, an absorption chiller, a control system, a thermal storage and a discharge system for rejected heat (Demlocs 2001). Depending on the application, one or more components are required. In Figure C16, there is shown a schematic diagram of the cooling centre in Helsinki.

* http://www.hightechfinland.com/2004/energyenvironment/helen.html

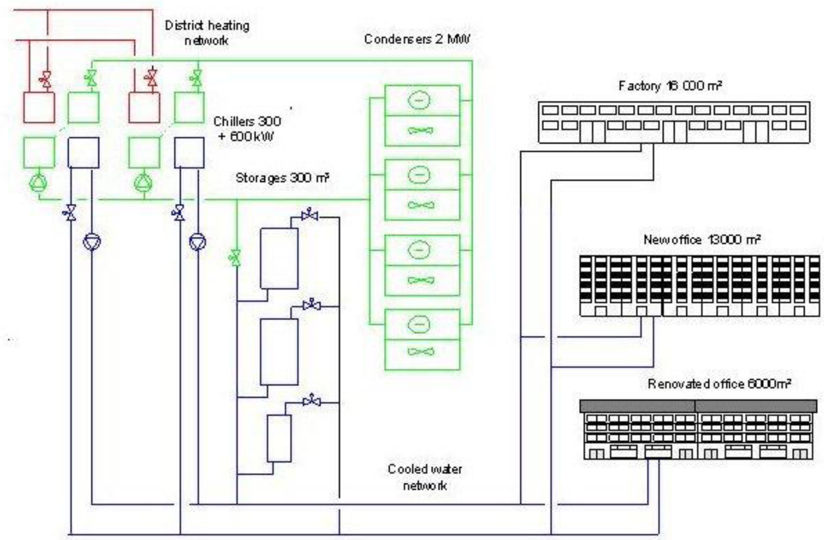


Figure C16. A simplified scheme of the cooling centre in Helsinki.

Basically, a cooling centre concept has the following advantages (Demlocs 2001):

- environmentally friendly refrigerant: water/salt solution or ammonia/water
- low maintenance cost
- high operational reliability
- no noise or vibration problems
- space requirement in the consumer's premises small
- all costs are predictable for the consumer
- long life-cycle ("green" refrigerant).

Figure C17 shows a principle layout of the Helsinki plant. Three different consumers are connected to the Local Cooling network; the Assembly area (15.000 m^2, left), a renovated office floor (6,000 m^2, background) and a new office building "Tellus" (12.000 m^2 office, right), which consists of six floors for car parking and four office floors. All together 13 pairs of ECONET units were installed in these premises and one existing air- handling unit was renovated as close to ECONET design as possible. The Energy Centre for cooling production is located beside the Assembly building (centre) about 20 m away from "Tellus" and 40 m from the renovated office floor.

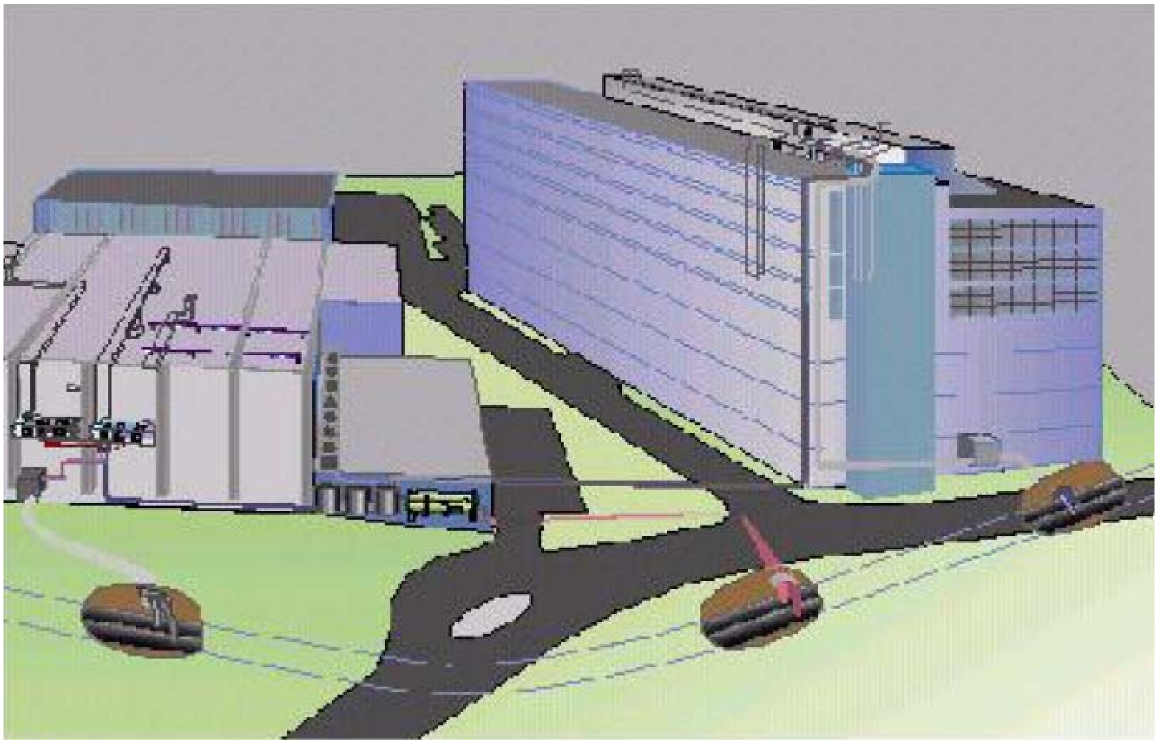


Figure C17. Principle layout of the Helsinki plant.

The pilot plant in Helsinki has a cooling capacity of 1.2 MW, using a series of absorption chillers and thermal storage. A schematic diagram of an absorption chiller is shown in Figure C18. The absorption chillers in this project used harmless water-lithium- bromide saline as refrigerant absorbent pair (Demlocs 1999). District heat boils off Boiler Condenser Absorber Evaporatorwater from the water-salt solution in the generator. The water steam flows then to the condenser and condensates. This water flows to the evaporator, operating in a high vacuum. The water evaporates instantly and cools down the water in the building cooling water network. The vapor goes then to the absorber, where it absorbs into the concentrated lithium-bromide solution returning from the generator. The diluted solution is then pumped back to the generator.

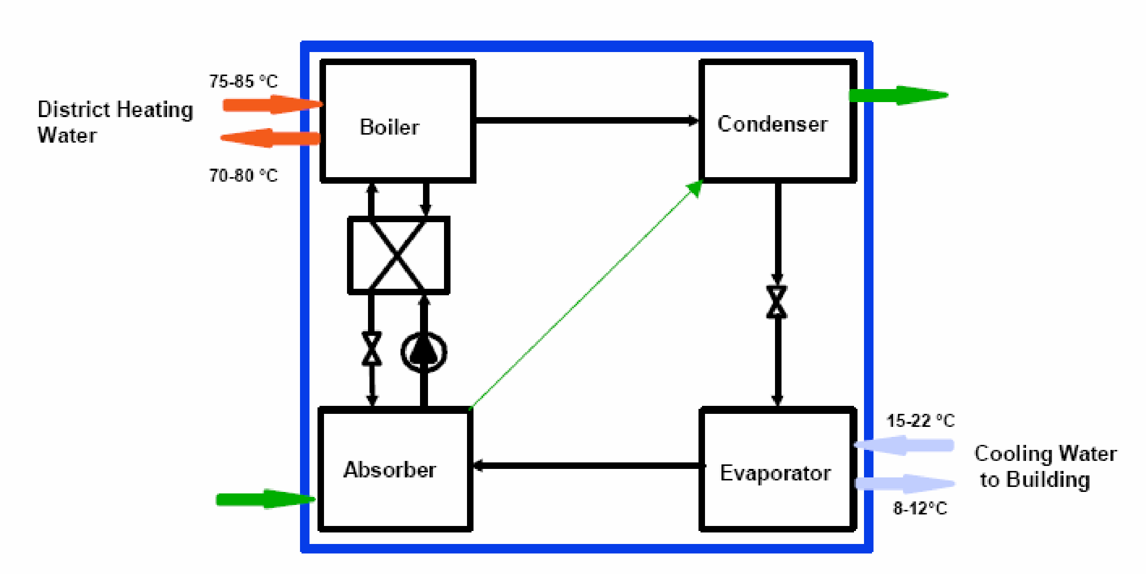


Figure C18. Absorption process.

The demonstration plant proved that with optimal design the average system-COP is at least 0.75 and running hours of the absorption chiller can be well over 1000 hours in cooling period even in comfort cooling in Finland (Demlocs 1999). The maintenance costs are low and the system can be remote controlled. A simple payback time for the energy operator in the future projects is estimated to be in the range of 5 to 10 years. The expected lifetime of the plant is over 20 years.

5.3 Other ECONET Energy Sources

5.3.1 ECONET® with Distributed CHP

The ECONET® system uses low temperature technology and can efficiently use low grade energies. So it can be connected to numerous energy sources including distributed CHP (Combined Heat and Power) (Figure C19).

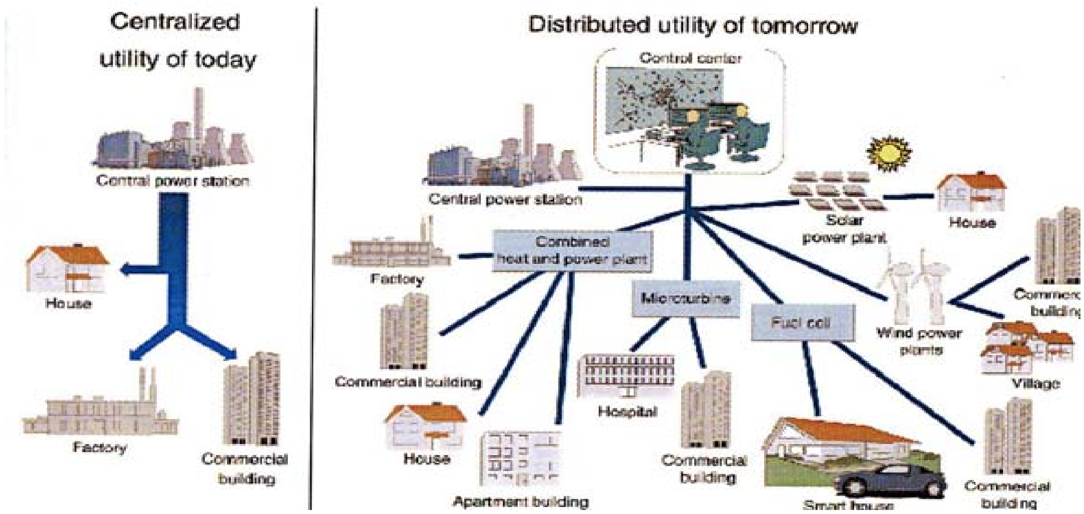


Figure C19. Integrated system solution may optimize functioning of distributed energy chains (Hyvärinen and Kohonen 2000).

The main advantages of connecting ECONET® to distributed combined heat and power (CHP) are its:

- use of cooling and waste energies of the CHP plant
- total optimized solutions such as LCC
- higher COP.

5.3.2 ECONET® with Solar Energy

The ECONET® system solution with solar heating is an integrated ensemble (Figure c20). Its starting points are (Hyvärinen & Kohonen 2000):

- efficient use of low temperature technology
- heat transfer medium at the level of 30 °C is adequate
- ability to be used (especially) during mid-terms in Finland
- ability to use solar heat, which covers most annual energy use
- integrated energy production and distribution
- higher solar gain factor.

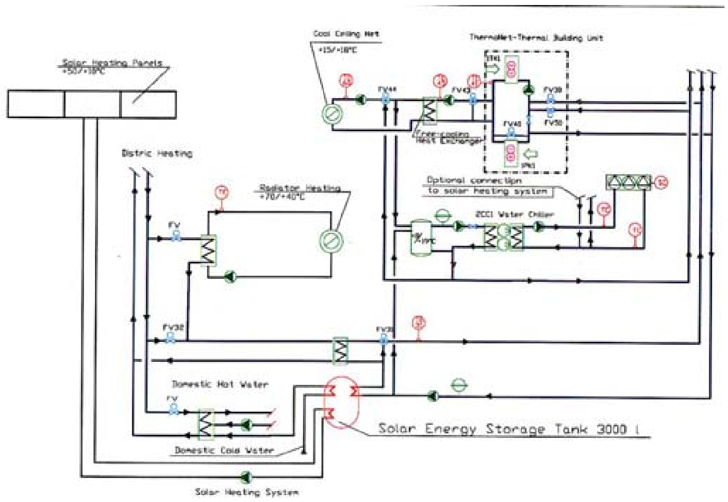


Figure C20. An ECONET connected to a solar heating system.

Advantages of the ECONET® system are that:

- It is an environmental friendly system.
- It makes maximum use of free energies.
- It has optimal life-cycle costs.
- It incorporates "green" values.

5.3.3 ECONET® with Ground Water

The energy the ground water holds can be put into profitable use by conducting the energy to cool down buildings and also, for instance, to heat them up with the help of a heat pump. Holopainen (1996) presents facts that are to be taken into consideration when constructing a ground water plant and connecting it to an ECONET system. Figure C21 shows a schematic diagram of an ECONET with ground water in a summer case.

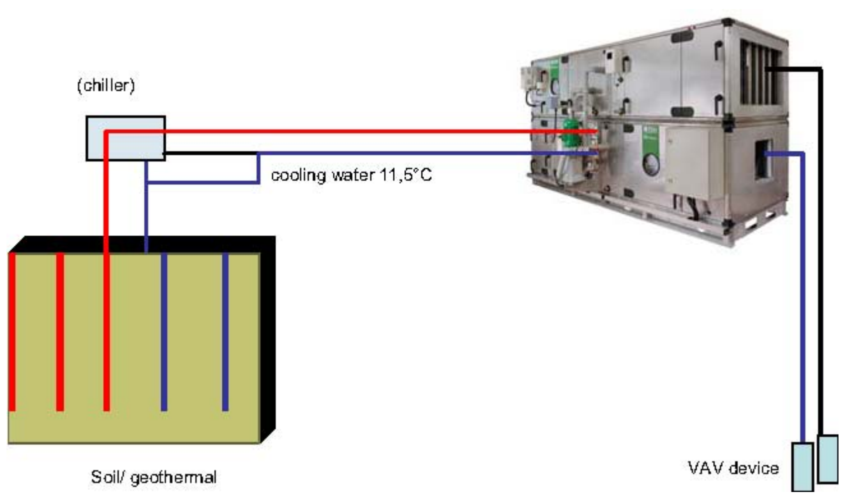


Figure C21. A principal of an ECONET using ground water for cooling.

5.3.4 ECONET® with Boilers

When sizing an oil boiler one has to consider that the return water from the ECONET air handling units, is cooler than the water that returns from the radiators or the "ordinary" AHUs. The supply water temperature of the oil boiler needs to be over 70 °C, so that the water vapor from the combustion gases will not condensate into the surfaces of the boiler and chimney, where it would cause corrosion. When the heat to the ECONET air handling unit is produced with a boiler, the water temperature difference is increased and the water flow is reduced compared to an "ordinary" system (Design Manual of ThermoNet Systems).

Certain fuels, for example wood chips and straw, do not consist of sulphur, so there is not a risk for corrosion caused by condensation. When these fuels are used it is possible to cool the combustion gas to lower than the condensation temperature with a condenser. As a result of the low return temperature the ECONET system suits well for use in context with a condensing boiler (Design Manual of ThermoNet Systems).

Comparison of a present boiler heating system and an ECONET boiler heating system

Sundman (1999) compared existing ventilation and air-conditioning units to the possibility to replace them with ECONET units in an existing hotel building in Manchester, UK. The heating capacity is provided with boilers and a CHP-plant.

The following features of standard ECONET units were used:
- heat recovery
- indirect evaporative cooling
- use of low temperature energy sources
- variable air volume (VAV) control.

The ECONET units were connected to a separate network where both heating and cooling capacities were added. The corresponding capacities were reduced from the primary heating and cooling nets. The supply temperature of the heating capacities to the ECONET units and reheating coils was 30 °C.

Design criteria are:

- Outdoor conditions:
    - Winter: -4.2 °C
    - Summer: 25.2 °C DB, 51.5 kJ/kg
- Indoor conditions:
    - Winter: 21 °C
    - Summer: 24 °C

CHP-plant design criteria are:

- The condensing capacities are used in the primary network in combination with the heating boilers.
- Spraying water cools the flue-gases. The energy recovered is fed into the ECONET circuit with a heat exchanger.
- The excess heat in the boiler room is cooled with the return water through a fan coil in the plant room.
- The overall (fuel) efficiency of the CHP-plant is increased by 30-40 percent.
- The estimations do not include the possibility to heat domestic hot water with heat capacity from the CHP flue-gas heat recovery.

Table C7 lists the estimated annual energy consumption with the traditional system and with the ECONET system (Sundman 1999). It can be noticed that the heating energy for the ECONET units is covered by heat recovery and CHP excess heat. In addition, the cooling energy consumption is reduced by 61 percent and the electrical energy for the fans is reduced by 58 percent, correspondingly.

Table C7. Annual energy consumptions.

Energy	Traditional System (MWh)	ECONET (MWh)	Difference (MWh)	Difference (%)
Heating	925.7		925.7	100
Cooling	125.6	49.4	76.2	61
Fans	685.8	289.7	396.1	58
Pumps	18.6	24.8	6.2	+33

It was estimated that the life cycle costs (LCC) of the ECONET system are 13 percent lower compared to the traditional system (Sundman 1999). At the time the study was made, the additional investment cost of the ECONET system was 120.000. However, the reduction in energy consumption gives a payback period of 3.4 years.

5.3.5 ECONET® with Heat Pump

The ECONET and a heat pump fit well together. The performance coefficient of the heat pump, which is the ratio of the used heat and the electricity used by the machinery, is better the lower the temperature difference is between the heat source and the system that uses the heat. With the low temperatures used in the ECONET installation, the heat pump functions constantly with a coefficient of performance as good as possible (Design Manual of ThermoNet® Systems).

5.3.6 ECONET® with Condensation Heat

Condensation heat is a convenient heat source for the ECONET system as long as the temperature level is convenient (at least 25 °C). If the temperature level is lower than this or there is not enough energy to cover the demand, the condensation heat can still be used, but an additional heat source is needed, for example primary water from the district heating (Design Manual of ThermoNet® Systems).

5.3.7 ECONET® with Electric Storage Heating

In electric storage heating the water is heated to a temperature of 90 to 95 °C with night electricity. The heat storage is sized so that the temperature in its upper part is still in the evening so high that the heat distribution system gets the needed heat from it. When using ECONET, the discharge temperature difference of heat storage can be more than 70 °C, in other words clearly higher than in an ordinary system, and the needed heat storage volume is reduced respectively. When the heat storage temperature is less than 60 °C the heat supply for the heating of domestic hot water has to be ensured with for example a separate heater (Design Manual of ThermoNet Systems).

6 Case Examples

6.1 Turku University Central Hospital

The extension to the Turku University Central Hospital (TYKS) named "T-Hospital" (Figure C22) has a total area of 21.600 m^2 and replaced the oldest hospital buildings, some of which are already more than 100 years old. The new extension includes dermatological and oncology clinics, pulmonary and surgery out-patient clinics, the new allergy unit as well as all the

medical services required by these clinics. Planning and designing of the new T-Hospital focused on meeting the needs of patients (Sundelin 2004). The ECONET system was selected to fulfill the special ventilation requirements of the hospital.

Figure C22. "T-Hospital" the extension to the Turku University Central Hospital (TYKS).

According to the HVAC-designer, the main reasons for choosing the ECONET system in the T-Hospital were that:

- There was a need to minimize space demand. (The ECONET air handling unit is about 1- 1.2 m shorter than a traditional AHU because the same coil is used for heat recovery, heating and cooling.)
- There was a need for energy efficiency. (Operating costs in a hospital are typically high due to the special requirements and large air volumes. So, energy efficient systems save a lot of money.)
- The system provides fully separated supply and exhaust air flows, which prevent cross-contamination.
- The system improves temperature efficiency compared to a traditional liquid circulated system.
- The system reduces district heat return temperature leading to reduced contracted water flow.
- The system increases cooling water return temperature.
- The system provides a large temperature difference in the liquid circuit, i.e., it requires smaller pipes and reduces costs.
- The T-Hospital had already had earlier experience with ECONET systems.

6.1.1 Dimensioning and Design Data of the T-Hospital

Table C8 through C13 summarize data pertaining to the main figures of the T-Hospital.

Table C8. Basic data of the T-Hospital.

Parameter	Measure
Cubic volume	126 796 m^3
Floor area	21 606 m^2
Heating system	District heating
Main cooling system	District cooling
Additional cooling	Cooling beams (not connected to ECONET), some local cooling devices
Ventilation system	ECONET
Heat distribution system	Water based radiator heating (electric heating if needed)
Number of ECONET in the building	44

Table C9. Main dimensioning temperatures.

Parameter	Measure
Dimensioning conditions:	
Outdoor temperature	26 °C
Indoor temperature	+ 23 °C
DH supply water temp.	+115 °C
DC supply water temp.	+8 °C

Table C10. Main dimensioning data of an ECONET.

Parameter	Measure
Air flow rate	2.7 m^3/s
Heat recovery	Liquid circulated system 30 % ethylene glycol 66 % temperature efficiency at 0 °C
Heating	Air temperatures 26/+22 °C
	Liquid temperatures 40/20 °C
Cooling	Air temperatures 25 °C (50 %)/18 °C
SFPv	1.79 kW/m^3/s
	Liquid temperatures 14/20 °C
Fan efficiency	Supply 79.7
	Exhaust 77.7 %

Table C11. Heat exchanger for heating.

Parameter		Measure	
Heating capacity	(kW)	49	
		Primary	Secondary
Flow	(l/s)	0.59	1.05
Supply temperature	(°C)	40	17
Return temperature (°C)		20	29
Pressure loss (kPa)		6	19
PHYSICAL DATA			
Number of elements		28	29
Water volume (l)		2.10	2.17
Additional heat transfer area (%)		105.11	
Heat transfer area (m^2)		4.00	
Weight	(kg)	15	
Material Data			
Liquid		water	30 % ethylene glycol
Specific heat	(kJ/kgK)	4,177	3,741
Density	(kg/m^3)	995.9	1037.5
Dynamic viscosity	(mNs/m^2)	0,799	2,269
Thermal conductivity	(W/mK)	0,614	0,490

Table C12. Heat exchanger for cooling.

Parameter		Measure	
Cooling capacity	(kW)	24	
		Primary	Secondary
Flow	(l/s)	0.88	0.96
Supply temperature	(°C)	14	23
Return temperature (°C)		20	16
Pressure loss (kPa)		16	14
PHYSICAL DATA			
Number of elements		27	28
Water volume (l)		2.02	2.10
Additional heat transfer area (%)		20.58	
Heat transfer area (m^2)		3.86	
Weight	(kg)	14	
MATERIAL DATA			
Liquid		Water	30 % Ethylene Glycol
Specific heat	(kJ/kgK)	4,186	3,730
Density	(kg/m^3)	998.5	1039.0
Dynamic viscosity	(mNs/m^2)	1,090	2,492
Thermal conductivity	(W/mK)	0,592	0,489

Table C13. Miscellaneous data.

Parameter	Measure
Extra boilers in building	None
Operating life of ECONET	25 years
ECONET connection to DH	Conventional DHconnection, dis- trict heat return water is not used
Pipe sizes in heat distribution system	63 80 mm [diameter]
Heat losses	Less heat loss due to lower temperature of circulating water

6.1.2 Consumption Data

Energy calculations

At the design phase, annual energy consumptions and energy costs of three ECONET units and comparable traditional air-handling units were calculated.

Conditions:

- Weather: Turku reference year
- Operating time: 24 hours/day, 365 days/year at full air flows
- Energy prices:
  - Heating energy: 24.11 /MWh
  - Electrical energy: 58.87 /MWh
  - Cooling energy: COP 3 (corresponding 19.68 /MWh).

Tables C14, C15, and C16 list data that summarize the calculated energy consumptions and energy costs for the three different cases. It can be noticed that even though the pumping energy and pumping energy costs increase significantly in all cases the total energy costs still decrease 19 to 28 percent with the ECONET units. It should also be noticed that the pumping energy of the traditional system is excluding the heating and cooling coil pumps. So the real pumping energy for the traditional system is bigger than in these calculations.

Table C14. The energy consumptions and energy costs for case A air-handling units.

	Traditional		ECONET		Reduction		
	Energy consumption (MWh)	Energy cost (€)	Energy consumption (MWh)	Energy cost (€)	Energy consumption (MWh)	Energy cost (€)	%
Fans	30.6	1801	29.9	1760	0.7	41	2 %
Energy, over 35 °C	94.9	2288	58.4	1407	36.5	880	38 %
Additional cooling	6.1	120	6.2	123	0.1	3	2 %
Pump	1.2	68	2.2	132	1	64	83 %
Total		4276		3422		854	20 %

Table C15. The energy consumptions and energy costs for case B air-handling units.

	Traditional		ECONET		Reduction		
	Energy consumption (MWh)	Energy cost (€)	Energy consumption (MWh)	Energy cost (€)	Energy consumption (MWh)	Energy cost (€)	%
Fans	52.9	3116	51.4	3024	1.5	92	3 %
Energy over 35 °C	166.6	4018	99.4	2398	67.2	1620	40 %
Additional cooling	9.2	180	9.3	183	0.1	3	1 %
Pump	0.8	44	6.2	367	5.4	322	675 %
Total		7358		5971		1387	19 %

Table C16. The energy consumptions and energy costs for case C air-handling units.

	Traditional		ECONET		Reduction		
	Energy consumption (MWh)	Energy cost (€)	Energy consumption (MWh)	Energy cost (€)	Energy consumption (MWh)	Energy cost (€)	%
Fans	88.7	5221	88.1	5188	0.6	33	1 %
Energy. over 35 °C	351.9	8487	165.2	3985	186.7	4501	53 %
Additional cooling	19.8	388	20.4	3	0.6	385	3 %
Pump	1.3	78	10.8	2	9.5	76	731 %
Total		14174		10207		3967	28 %

Realized consumption data of the whole building

Table C17 summarizes the consumption data of the T-Hospital in 2004. It is difficult to compare the energy consumptions because a representative reference does not exist. There are not calculated target values and previous history is not yet available. In 2004, the specific heating energy consumption of the main hospital, built in 1960's, was 76.08 kWh/m^3 and the specific heating energy consumption of the surgical hospital, new building also including ECONET systems, was 59.15 kWh/m^3. So, the specific heat-

ing energy consumption of the T-Hospital 39.06 kWh/m^3 seems to be quite small. In 2005, the energy price for both heating and cooling is 29.65 /MWh.

Table C17. Consumption data in 2004.

Parameter	District cooling	District heating
Consumed energy (MWh]	1,500	4,953
Specific consumption (kWh/m^3]	11.83	39.06
Basic fee (Water flow charge) (€]	30,947	33,172
Consumption fee (€]	39,195	128,428
Contracted capacity (MW]	1,640	5,700
Contracted Water flow (m^3/h]	141	70
Connection fee (paid in 2003) (€]	91,738	66,860

6.1.3 Additional Information

System control

A heat transfer liquid changes temperature as it gains or loses heat energy without changing to another phase. The ideal heat transfer fluid is water, with obvious limitations due to freezing and boiling point conditions. The conventional heat transfer liquid used in the heat recovery system is ethylene glycol (25-35 percent water/ethylene glycol mixture). The heat recovery is maximized when the heat capacity flow of incoming and return flows are similar (Tielinen 1997).

ECONET circuit's liquid flow is controlled by the frequency inverter for the pump and by an ECONET controller. The controller is equipped with software that optimizes the circulation flow in the circuit to each operating condition. The software in the controller includes protection and alarm functions. ECONET controller is fully controlled by AHU's main controller and does not need any direct intervention from the display. Display is used for setting parameters and for diagnosing reasons for faults (ECONET manual 2005).

Figure C23 illustrates the air temperature control of an ECONET air-handling unit in the T- Hospital. The ECONET circuit is part of the supply air temperature control. With the frequency controlled pump, the liquid flow of the ECONET circuit is always kept in the area where the temperature efficiency is optimal.

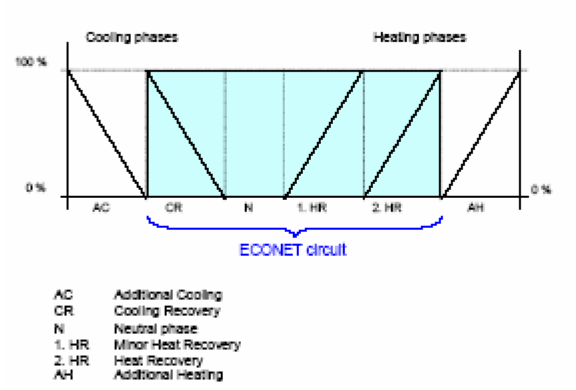


Figure C23. The temperature control phases of an ECONET air handling unit.

Figure C24 illustrates the principle of the supervisory control of an ECONET air handling unit in the T-Hospital. The supply air temperature setpoint is changed based on the room air temperature measurement and possibly based on user demand. Then, the supply air temperature is controlled as described previously in Figure C23. In operating theaters, the indoor air humidity is also measured and the supply air humidity setpoint is changed if needed. Normally, the air flow rate is controlled based on operating schedules but it can be increased/decreased on request.

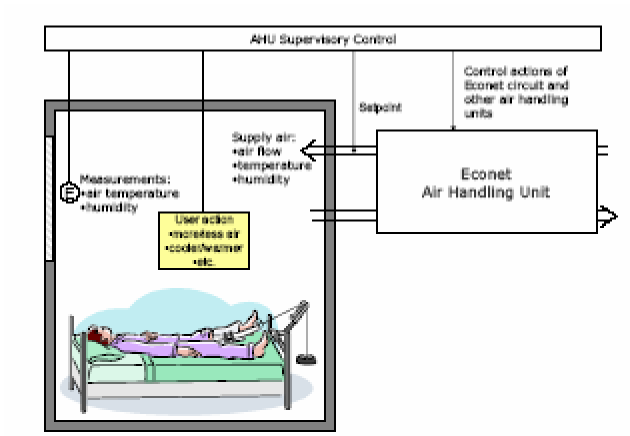


Figure C24. A principle of the supervisory control of an ECONET air handling unit in the T-Hospital.

System Reliability

In hospitals, system reliability is extremely important. The best, secure, and reliable technology is used. In the T-Hospital, all the technical systems have backup systems for system failures and breakdowns. In addition, there is own well-trained service and maintenance personnel.

ECONET has less inner components than a traditional system. During the 2.5 years operating time only one break has occurred. It was a break in district cooling that was announced in advance. In district heating, no defaults have occurred.

Maintenance costs of system

There is no data available of the maintenance costs. However, it can be estimated that the maintenance costs do not vary compared to a traditional system.

6.2 Sibelius Hall, Lahti, Finland

Sibelius Hall is the largest wooden building constructed in Finland for over 100 years (Figure C25). The large complex (nearly 90.000 m^3) is a congress and concert centre and includes the main hall (1250 seats), forest hall (1000 m^2 lobby), a renovated carpentry factory (1400 m^2) for exhibitions and meetings and lecture rooms. Wood has always been a popular building material in Finland, both inside and outside. The Sibelius Hall was however a big effort to develop the timber construction technology even further (Ala-Juusela 2004).

6.2.1 General Description

The building is cooled and heated with an ECONET system, which is an integrated system concept for air handling, heating and cooling. It operates at low temperatures for heating and high temperatures for cooling. The energy to the Sibelius Hall is delivered by district heating and district cooling networks. The energy source for cooling is the local industry process water via absorption chillers. Waste heat from the system is recovered to the district heating return.

The building contains many special wooden elements and new solutions. For example the facades of the congress and concert hall are made of sand filled wooden elements and glass. Recent research in Finland has shown that wooden materials have a positive effect on indoor climate and comfort. A lot of attention is paid to the acoustics of the main hall. The materials and even the furniture are chosen bearing in mind their effect on the acoustic qualities of the hall. In this kind of environment it is also very important that the cooling system is silent. The echo chambers at the sides of the hall with their doors and curtains make the acoustics of the hall adjustable.

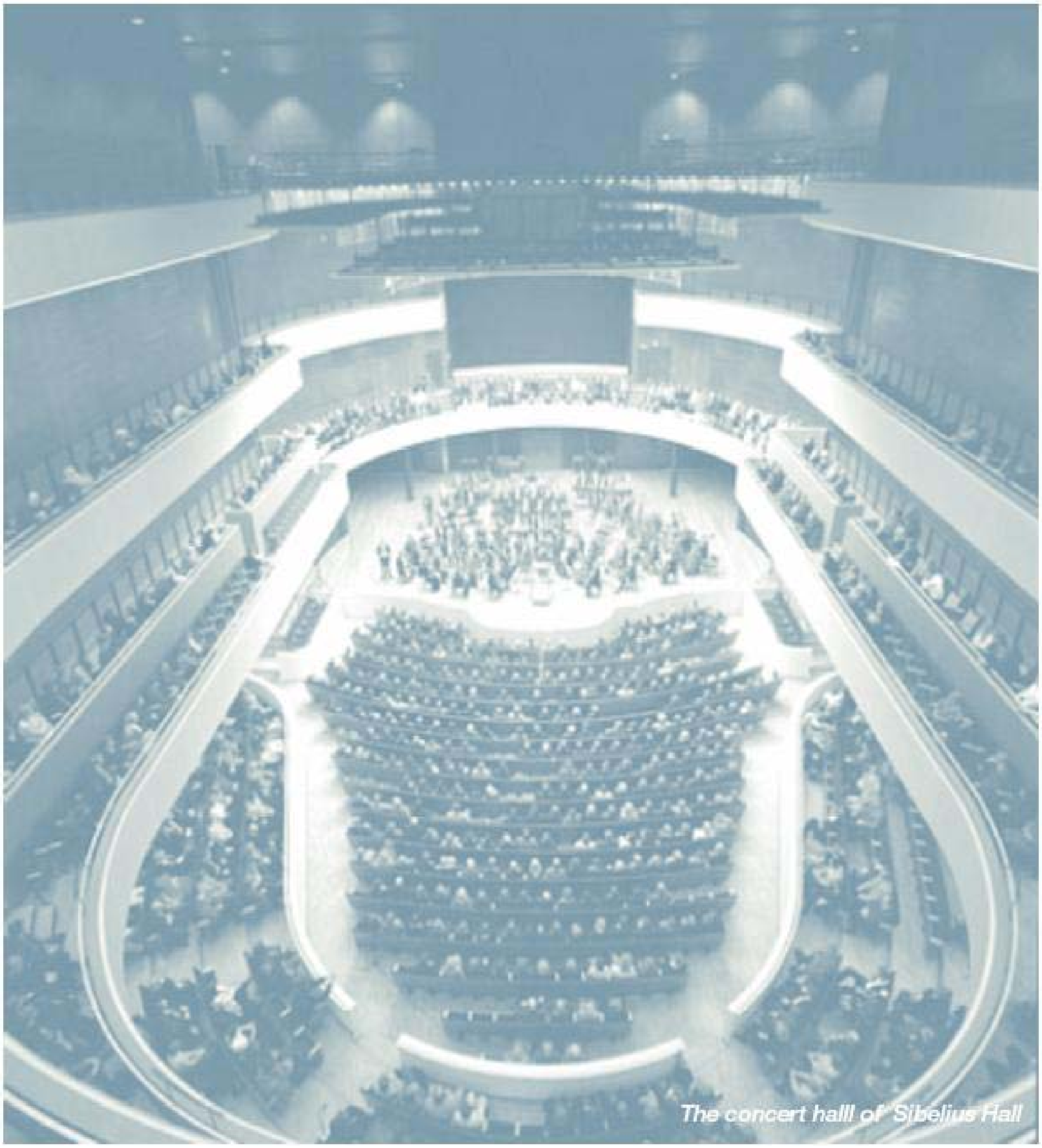
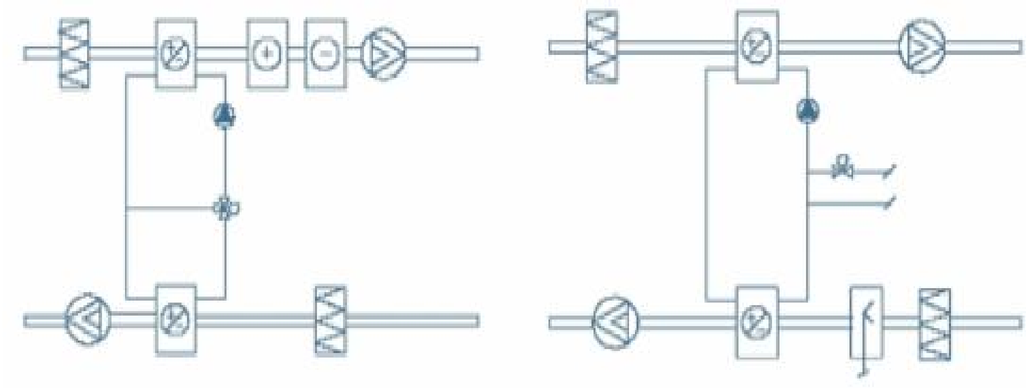


Figure C25. The concert hall of Sibelius Hall.

Installation Scheme

The key idea of ECONET is to combine heating, cooling, heat recovery and the use of waste heat to a single circuit (Figure C26). System is based on small temperature difference and large heat transfer surfaces. Cooling power to the incoming air is provided by evaporative cooling of exhaust air. Return water has nearly the same temperature in both systems and pipes, therefore only one pipe is required.



Traditional system on the left, Thermonet on the right.

Figure C26. Traditional and ECONET (previously Thermonet) systems.

6.2.2 User Experiences

Users and maintenance personnel were interviewed to find out comfort levels of the building. Users were generally satisfied with the building services and maintenance personnel told that automatics were functioning properly. However, heating energy and electricity consumptions in 2001 were much higher than expected. The building had many construction faults, which took long to correct. Mainly there were a lot of structural problems, especially with the facade glazings. There were also some problems with the condensation of moisture to windows, which lead to freezing problems. Ventilation system created under-pressure to the congress area and made doors open unless locked. Some problems are now fixed but there is no measured information about the results available.

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Annex 1: District Heating Water Flow Charge in Helsinki, Finland

Contract Water Flow	Water flow charge from 1.1.2005			
	Including VAT 22%		Without VAT	
M³/h	€/year	€/month	€/year	€/month
0	0.00	0.00	0.00	0.00
0.10	210.69	17.56	172.70	14.39
0.15	316.04	26.34	259.05	21.59
0.20	421.39	35.12	345.40	28.78
0.25	526.74	43.89	431.75	35.98
0.30	632.08	52.67	518.10	43.18
0.35	719.13	59.93	589.45	49.12
0.40	807.40	67.28	661.80	55.15
0.45	895.66	74.64	734.15	61.18
0.5	983.93	81.99	806.50	67.21
0.6	1160.46	96.71	951.20	79.27
0.7	1337.00	111.42	1095.90	91.33
0.8	1513.53	126.13	1240.60	103.38
0.9	1690.07	140.84	1385.30	115.44
1.0	1866.60	155.55	1530.00	127.50
1.2	2219.67	184.97	1819.40	151.62
1.4	2572.74	214.39	2108.80	175.73
1.6	2925.80	243.82	2398.20	199.85
1.8	3278.87	273.24	2687.60	223.97
2.0	3631.94	302.66	2977.00	248.08
2.2	3894.48	324.54	3192.20	266.02
2.4	4157.03	346.42	3407.40	283.95
2.6	4419.57	368.30	3622.60	301.88
2.8	4682.12	390.18	3837.80	319.82
3.0	4944.66	412.06	4053.00	337.75
3.2	5207.20	433.93	4268.20	355.68
3.4	5469.75	455.81	4483.40	373.62
3.6	5732.29	477.69	4698.60	391.55
3.8	5994.84	499.57	4913.80	409.48
4.0	6257.38	521.45	5129.00	427.42
4.4	6782.47	565.21	5559.40	463.28
4.8	7307.56	608.96	5989.80	499.15
5.2	7692.83	641.07	6305.60	525.47
5.6	7977.34	664.78	6538.80	544.90

Contract Water Flow	Water flow charge from 1.1.2005			
	Including VAT 22%		Without VAT	
M³/h	€/year	€/month	€/year	€/month
6.0	8261.84	688.49	6772.00	564.33
6.4	8546.34	712.20	7005.20	583.77
6.8	8830.85	735.90	7238.40	603.20
7.2	9115.35	759.61	7471.60	622.63
7.6	9399.86	783.32	7704.80	642.07
8.0	9684.36	807.03	7938.00	661.50
8.4	9968.86	830.74	8171.20	680.93
8.8	10253.37	854.45	8404.40	700.37
9.2	10537.87	878.16	8637.60	719.80
9.6	10822.38	901.86	8870.80	739.23
10	11106.88	925.57	9104.00	758.67
11	11818.14	984.85	9687.00	807.25
12	12529.40	1044.12	10270.00	855.83
13	13240.66	1103.39	10853.00	904.42
14	13951.92	1162.66	11436.00	953.00
15	14663.18	1221.93	12019.00	1001.58
16	15104.82	1258.74	12381.00	1031.75
17	15609.90	1300.83	12795.00	1066.25
18	16114.98	1342.92	13209.00	1100.75
19	16620.06	1385.01	13623.00	1135.25
20	17125.14	1427.10	14037.00	1169.75
22	18135.30	1511.28	14865.00	1238.75
24	19145.46	1595.46	15693.00	1307.75
26	20155.62	1679.64	16521.00	1376.75
28	21165.78	1763.82	17349.00	1445.75
30	22175.94	1848.00	18177.00	1514.75
32	23186.10	1932.18	19005.00	1583.75
34	24196.26	2016.36	19833.00	1652.75
36	25206.42	2100.54	20661.00	1721.75
38	26216.58	2184.72	21489.00	1790.75
40	27226.74	2268.90	22317.00	1859.75
42	28236.90	2353.08	23145.00	1928.75
44	29247.06	2437.26	23973.00	1997.75
46	30257.22	2521.44	24801.00	2066.75
48	31267.38	2605.62	25629.00	2135.75
50	32277.54	2689.80	26457.00	2204.75
52	33287.70	2773.98	27285.00	2273.75
54	34297.86	2858.16	28113.00	2342.75
56	35308.02	2942.34	28941.00	2411.75

Contract Water Flow	Water flow charge from 1.1.2005			
	Including VAT 22%		Without VAT	
M³/h	€/year	€/month	€/year	€/month
58	36318.18	3026.52	29769.00	2480.75
60	37328.34	3110.70	30597.00	2549.75
70	42379.14	3531.60	34737.00	2894.75
80	47429.94	3952.50	38877.00	3239.75
90	52480.74	4373.40	43017.00	3584.75
100	57531.54	4794.30	47157.00	3929.75
110	62582.34	5215.20	51297.00	4274.75
120	67633.14	5636.10	55437.00	4619.75
130	72683.94	6057.00	59577.00	4964.75
140	77734.74	6477.90	63717.00	5309.75
150	82785.54	6898.80	67857.00	5654.75
160	87836.34	7319.70	71997.00	5999.75
170	92887.14	7740.60	76137.00	6344.75
180	97937.94	8161.50	80277.00	6689.75
190	102988.74	8582.40	84417.00	7034.75
200	108039.54	9003.30	88557.00	7379.75
220	118141.14	9845.10	96837.00	8069.75
440	229258.74	19104.90	187917.00	15659.75

Annex 2: District Heating Survey Form

District heating survey form

General Information

District Heating System Name ______________________________

Location: Turku, Finland

Type of Buildings served Residential buildings, office buildings, Hospitals etc.

Number of buildings and total area served: DH is the most common heating form in Turku (90 %). It covers nearly all suburbs and urban areas. More than 150 000 people live in district heated houses.

Supply and Return temperatures: Typically supply 75ºC-115ºC and return 45ºC-55ºC

Central Heating System: Turku Energia

Number and size of boilers: District heat is produced mainly in Naantali CHP plant, Turku waste incineration plant, bio heating plant and other heating plants.

Type of fuel(s): Coal, gas, waste, wood, biofuel, oil

Maximum load: Naantali CHP plant 945 MW (fuel power)

Annual energy consumption: District Heating 1 635 GWh, District cooling 6,1 GWh

Generated fluid: _________

Pressure & temperature: The pressure and the pressure difference in the district heating network vary all the time. The pressure difference of at least 60 kPa (0.6 bar)is guaranteed to the client by the heat producer.

No. employees 300

Have steam driven turbine/generators: ___ pumps: Electrical fans: Electrical Other: Combustion gas system

Type of chemical treatment system: Oxygen feeder, colorant for recognizing leaks

Chemical treatment cost: about 1 € / liter

Percent blowdown: ______________________________

Heat recovery systems:

Combustion air preheater In a boiler unit preheated by air / economizer

Make-up water preheater Doesn't exist

Boiler feed water preheater exist, additional water tank may exist

Boiler controls: normal control of air, water and pressure

Oxygen trim water test periodically in small plants, big plants have it

What are the boiler turn down ratios depends on boiler type, basic boiler's about 3000 h/a

Distribution system pumping system pressure containment system

variable flow? the pump's speed of rotation is regulated

Seasonal temperature adjustments:

Outdoor temperature control: Winter max 115 °C Summer max 75-80 °C

If temperature varied hourly, length of time for adjustment to reach all buildings:
Adjustment delay 1-3 h depending on the network, flow speed 3 m/s___
How were the number of boilers sized ________________________________
Is there a standby/backup boiler? _usually lightweight boilers for peak usage_________

District heating survey form

Distribution System

Pipe materials and insulation: Steel or Plastic (low temperature-cases) pipes, inside buildings also copper pipes
Manufacturer(s) of pipe materials: _KWH pipe (domestic)_
Does this manufacturer serve the US market?_Not sure, but they export products______
Is there an alternative piping manufacturer?_Yes_ If so, who is it? _For example Nordic markets___
Installed cost _varies depending on the pipe size_ Cost/ meter installed _1000 m€/m (outgoing and return pipes)
Have any of the pipes been replaced with new materials _______
If so, what type _old concrete pipes are renewed all the time
Was there difficulties connecting new system to old? _succeeded with adapters, occasionally problems
Pipe placement: Underground at a depth of 0,5 - 1,0 m trenches ___ overhead ____
Other ____
Range of fluid flow: The volume flow is adjusted, to achieve a certain pressure difference
Length of pipe in system District heating network 299 km, District cooling network 6-8 km
Pipe size: Vary between 50 mm (A building's service line) and 800 mm (A production plant's supply line)
Temperature drop through pipe to buildings: _a few degrees 2-3 °C, max 5 °C
Pipe expansion system: _fixed to the ground, U-link, Z-link
Age of piping system: _20-30 years, even > 50 years, depends also on the installation 55-60 years
Annual maintenance activities: _Annual maintenance is done during summer
Cost of annual maintenance: ________________________________
Expansion joint problems: _if properly planned, there isn't any problems with thermal expansion
Piping leak history: The delivery reliability of district heating is almost 100 %. The district heat client is without heat during one hour per year on average due to damages_ in the district heat networks and operational shutdowns during repair work. In the T-hospital, during 2,5 years, there has been one break in district cooling, which was

informed of in advance, and no breaks in the district heating network. The heat losses in pipelines are typically 5-6 %.

Pipe repair methods: Usually the pipes are renewed, but it depends on the pipe material and location

Frequency of component replacement: It depends on the component, but most ones tolerate up to 50 years of usage. Valves need to be changed more often; in 10-15 years

Protection from freezing: The pipelines are thermally insulated efficiently and functions well in cold climates, like Finland

If underground, how protected from corrosion Covered with a plastic core shell, so that water can't get through

Is there continuous flow through all pipes: The pressure difference between the supply and return pipelines makes the district heat flow in the district heat network and in the client's district heat substation.

District heating survey form

Building Interface

Building type: Hospital Size: 21 600m^2

Distance from heating plant

Entering fluid temperature: Heating 65 - 115 °C, Cooling + 8 °C

Leaving fluid temperature: Heating 40 - 60 °C, Cooling 14 - 15 °C

Function/Process with hottest temperature demand Req'd temperature

Other heating energy users

Heat exchanger types

Any reboilers No If yes, req'd pressure Function

What is the efficiency of the reboiler unit

Problems with heat exchangers

Is temperature adjusted by season: Yes

Is temperature adjusted by daily demand: Yes

Summertime heat exchanger effectiveness

Type of controls

What is sensed/measured: Based on the measurements from the flow sensor and from the temperature sensors the heat amount counter calculates the heating energy used for space heating and for hot service water. The used heating energy is measured in megawatthours (MWh).

How is leaving temperature varied

Problems with controls

Annual maintenance activities: Not much, the activities are taken care of by own employees regularly

Cost of annual maintenance:

Frequency of component replacement: It varies according to the component, typically heat exchangers are replaced every 20-30 years

If low temperature system with no heat exchanger, any problems ___________________

Do hot water consumers have any cost incentive that would affect their use? No

How are consumers billed? The energy plants bill according to the amount of consumed energy

Appendix D: Working Order for a Tri-Generation (Power, Heat and Cooling Energy) Plant

Introduction to the Consortium

The Alstom Energietechnik GmbH company, in connection with the worldwide operating Alstom concern, is successfully active in the field of decentralized power supply in Bremen as plant constructor both in energy transfer and distribution. Kraftanlagen Anlagetechnik Heidelberg GmbH, an enterprise of the GAH Beteiligungs AG, Heidelberg, has been active for generations as a service enterprise specialized in the piping equipment and construction.

General Information to the Project

In January 2000, Harpen Energie Contracting GmbH's (HEC's) bid successfully won (in a Europe-wide solicitation) to take over the Heat and Cooling supply to the University Clinic Heidelberg "Im Neuenheimer Feld" for 25 years. HEC's offer planned not only the heat and steam supply, but also a central cooling supply and a possible electrical supply. This power-heat-cooling concept was developed in close co-operation between the GEF Ingenieur AG and HEC, in which GEF engineer AG furnished the design work. Table D1 summarizes HEC's schedule to provide heat and cooling to the University Clinic Heidelberg.

Table D1. HEC's schedule to provide heat and cooling to the University Clinic Heidelberg.

Date	Activity
April 2000	Take over the existing heat plants.
May 2001–March 2002	Establish tri-generation plant and the new district cooling network through Alstom Kraftanlagen Anlagentechnik Heidelberg.
April 2002	Augment the existing heat supply at the university clinic with a cooling supply
April 2002	Begin power supply of about 13.5 MW_{el}.

The Harpen Energie Contracting GmbH supplies all equipment to the University Clinic Heidelberg INF (the German cancer research institute) and to the newly built Technology Park III, and annually provides:

- 140,000 MWh heat for hot water production and space heating.
- 13,000 MWh steam for Sterilization, kitchen, and laundry needs
- 26,000 MWh cooling energy for air conditioners and coolers.

Some basic core components were:

- Gas turbine with an electrical capacity of 13.5 MW_{el} and a thermal capacity of about 20 MW_{th}
- Waste heat boiler with an auxiliary capacity of maximum 38 MW_{th}

- Two heat accumulators of 150 m^3
- Cooling central with a maximum cooling capacity of 35 MW_{kt} in Endausbau
- Two Cold storage of 200 m^3
- Cooling network of about 3.5 km long (Trench) laid in underground and in Canal.
- Ten cooling transfer stations connecting to the Technology Park III for a supply of about
  - 6.7 MW Heat
  - 7.0 MW Cooling energy
- Complete electrical and control technology providing all necessary construction for the cooling plant of size: 30 x 16 x 10 m (L x W x H).

The cooling and electrical supply was scheduled to begin in April 2002, to coincide with the completion of the above-mentioned plants and buildings. The consortium Alstom/Kraftanlagen Anlagentechnik Heidelberg was tasked with a very demanding project, one that incorporates an extensive, innovative technology, in a short time, in the sensitive environment of the university clinic. GEF Ingenieur AG's detailed planning enabled HEC to meet the demands of the tight schedule. The bid further economized the project by merging the functionalities of the electrical and the control systems (Alstom) in the piping and equipment construction (Kraftanlagen Anlagentechnik). Furthermore, since Kraftanlagen Anlagentechnik Heidelberg had built the existing Heat plant some 30 years before, its participation was instrumental in the successful realization of the new project.

Technology

The future district heating and cooling supply for the university clinic "Im Neuenheimer Feld" (INF) will use gas turbines to augment the existing heat plant and to concurrently produce electric current through power and heat coupling. The Gas turbines have the following capacity:

- Firing thermal capacity: ~37 MW
- Electrical capacity: ~13.5 MW
- Thermal capacity: ~20 MW without Booster (with 120 °C waster gas temperature)

Natural gas and fuel oil (as an alternative) is used as fuel. Exhaust gas from the gas turbine are fed into the booster connected in series. An additional 18 MW firing thermal output in the waste heat boiler can be produced using an auxiliary firing (Booster) in the waste gas system, by burning the remaining oxygen content with the ~500 °C exhaust gas. Steam

and hot waters are produced in the waste heat boiler, which are then fed into the network of university clinic INF. Due to this measure, the existing 25- and 28-year-old hot water and steam boilers continue to be used as reserve and peak boilers.

The gas turbines with waste heat boiler will take over the basic future load supply and the existing heat plants will cover the peak load in the university area “Im Neuenheimer Feld.”

The past decentralized compression cooling plants (partly needs renewal) are replaced by a central cooling. The cooling plant is established with an absorption cooling system (2 machines at 5 $MW_{chilled}$) for the basic load supply and three compression cooling machines/turbo machines at 5 $MW_{chilled}$ for peak load cover on the heating station area in a new building in direct proximity to the existing heating house (cf. the plan in Appendix A).

Cooling energy is needed year round.

Cooling distribution is achieved using a newly installed district cooling distribution network connecting individual cooling plants on the university campus. (See the overview of the cooling network in the Appendix A.)

The following boilers are currently installed in the heating station:

- two steam boilers
  - Nos. 1 and 2
  - year of construction: 1972
  - firing thermal capacity: 9.5 MW each.
- three hot water boilers
  - Nos. 3, 4, and 5
  - year of construction: 1974
  - firing thermal capacity: 31, 41, and 41 MW.

After the new waste heat boiler was ready to operate, Boilers No. 2 and 4 were removed from the existing boiler plant network and held in reserve. Boiler 5 was also removed from the network and shut down completely. (No. 5, however, is still available as an emergency reserve.)

Boilers No. 1 and 3 remain as constant reserve and for peak load coverage.

By taking the measures described above and by lowering the temperature at the university, there should be no need for all production units to operate at the same time.

Effects of the Project on the Rhein-Neckar-Region

Emission

The use of the Power-Heat-Cooling-coupling plant (tri-generation-plant) will replace the existing gas/fuel oil-beaconed boiler plant and produce heat as a byproduct. This means that the local fuel input will rise. This substantially improves the global/regional CO_2-balance due to the coupled production of power and heat. A further improvement of the CO_2-balance results from the fact that the existing decentralized compression cooling plants (driving power: Electricity) is replaced as much as possible by the absorption cooling (driving power: Waste heat of the gas turbine).

The plant's high efficiency will make optimal use of the assigned fuel and minimize flue gas emissions. Gas turbine exhaust gases are fed to the waste heat boiler, and are exhausted afterwards through the new chimney. The exhaust gas leaves with a temperature of approximately 120-140 °C from the chimney. The maximum specific emissions (related to 15 percent O_2 by volume in the exhaust gas) for gas turbines with natural gas as fuel, in accordance with the values of the TA Luft (intensified requirements), amount to:

- Carbon monoxide (CO) 100 mg/Nm³
- Nitrogen oxide (NO_X) 150 mg/Nm³

Grime No. 2 must be maintained in continuous operation.

The maximum specific emissions (related to 15 percent O_2 by volume in the exhaust gas) for HEL, in accordance with the values of the TA Luft (intensified requirements), amount to:

- Carbon monoxide (CO) 100 mg/Nm³
- Nitrogen oxide (NOX) 200 mg/Nm³
- Sulphur oxide (SO) The liquid fuel may contain proportion of sulphur in accordance with DIN 51603 Pt 1.

The planned plant will easily maintain the above mentioned Limit values of the TA Luft.

The estimated emission values (total cost), calculated by the TÜV Mannheim, clearly lie below the TA Luft specified "emission values to the protection from health dangers." This can be seen from the comparison of the emission values enclosed in the attachment.

These diagrams are provided under the condition that fuel oil is used to fuel the tir-generation plant. Fuel oil is however considered an alternative fuel, natural gas is the primary fuel. The emission situation represented in the diagrams is thus a "Worst Case" representation, i.e., a projection of the maximum possible emission. Actual emissions will be lower.

A Continuous-emission measuring instrument is to be built into the gas turbine exhaust stream, attached to the existing emission remote supervision in the heating station, to be made available on-line to the trade supervisory board Mannheim for monitoring purposes.

In coordination with these construction plans, the university waste incineration plant (AVA) was shut down and dismantled by Kraftanlagen Anlagentechnik Heidelberg. This improved emissions at the Heidelberg location, relative to statements in the available TÜV Mannheim report.

Noise

The gas turbine system is placed in a sound-proofing enclosure, which also protects the gas turbine against weather disturbance. Sound absorbers are also configured in the air intake and exhaust openings of the ventilation systems, the cooling back plants, and the waste gas flues. Furthermore the (fuel, waste gas, etc.) systems connected to the gas turbine are decoupled over compensators to limit sound transmission. These measures will ensure that the plant maintains noise within allowable noise radiation limits in the environment, i.e., that it operates quietly.

TÜV Mannheim examined and evaluated the sound proofing measures and the effects on the environment and determined that the requirements of the TA Lärm must be preserved at all points of emission. In general, all acoustic sources that exceed the standards will be provided with sound-proofing measures.

Interferences to the Nature

It was determined that some trees must be cut down near the future cooling plant. After consulting with the Heidelberg environmental office, it was

decided to compensate for this reduction in the tree population by planting new trees in a suitable place. Beyond this, no further environmental interferences are anticipated.

Further Inquiry / Contact Persons

Should the questions arise after reviewing the available short description, the Consortium, Contractor, and Planner are available for further inquiries.

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List of Enclosures

- Layout plan Gas turbine and Cooling central
  Overview cooling network University Campus INF
- Comparison of Emission values in Heidelberg

- Comparison of Emission values in Heidelberg however without Carbon monoxide and org. materials (supply to University clinic INF with a tri-generation plant).
- To compare: Supply to University clinic INF with a conventional plant

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14. ABSTRACT

"District heating" (DH) is much less common in the United States than in Europe, where it is widely accepted as a method for providing safe, efficient, low-cost heating energy to the consumer. This study investigated and evaluated experiences with DH systems in Europe, focusing on systems in Germany and Finland, to offer recommendations for improving U.S. Army DH systems in the Continental United States (CONUS), specifically to evaluate the feasibility and economics of converting existing systems, to reduce heat and water losses, to improve thermal efficiencies, and to reduce the high cost of pipe replacement. This work investigated technical details of energy plant and DH systems, including some U.S. Army and municipal district heating systems in Germany, and recommended that CONUS Army central energy plants be investigated for conversion to cogeneration facilities, with sliding temperature-variable flow of medium/low temperature hot water as a heating source.

15. SUBJECT TERMS

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